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CONTENTS

	PAGE
Institution Notices	I–VIII
Notes on the Petroleum Geology of Western Canada. A. J. Goodman, B.Sc., Ph.D.	221
One Hundred and Sixty-third General Meeting .	259
Annual Report of the Council, 1934 . . .	274
Annual General Meeting	285
Effects of Geophysical Factors on the Evolution of Oil and Coal. David White	301
Abstracts	109a
Books Reviewed and Books Received . . .	144a

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The Institution as a body is not responsible for the statements of opinion expressed in any of its publications.

Copyright.—Publication of abstracts of Papers and articles appearing in the Journal is permitted, provided that acknowledgment is made to the Institution of Petroleum Technologists.

Papers and Articles.—The Council invites Papers and Articles both for reading at Ordinary Meetings of the Institution and for publication in the Journal. All Papers, whether for reading or publication, will be submitted to a referee appointed by the Publication Committee.

The Institution has published a brochure "Instructions for the Guidance of Authors" containing details of recommended practice in the preparation of Papers for publication. Copies of this brochure will be supplied on request.

Pre-Prints.—Advance proofs of Papers to be read at Ordinary Meetings are generally available about a week before the Meeting. Members wishing to be supplied with these pre-prints are requested to notify the Secretary.

Abstracts.—Members and Journal Subscribers desirous of receiving the Abstracts printed on one side of the paper only, can be supplied with these at a charge of 10*s.* per annum per copy, payable in advance.

Issue of Journal.—Members whose subscription is not in arrear receive the Journal free of cost. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

Changes of Address.—Members are requested to notify any change of address to the Secretary.

Benevolent Fund.—The Benevolent Fund is intended to aid necessitous persons who are or have been members of the Institution, and their dependent relatives.

The Fund is raised by voluntary annual subscriptions, donations, and bequests, and all contributions should be sent to the Secretary of the Institution at Aldine House, Bedford Street, London, W.C. 2. The Fund is administered by the Council through the Benevolent Fund Committee, and all applications in connection therewith must be made on a special form which can be obtained from the Secretary of the Institution.

Appointments Register.—A register of members requiring appointments is kept at the offices of the Institution, and every effort is made to assist members of the Institution in search of employment.

Members who desire their names and qualifications to be included in this register are requested to apply to the Secretary for the Form of Application for Registration, if they have not already done so. Members residing in the London area are asked, if possible, to return this Form in person and make themselves known, together with their requirements, to the Secretary. It is also requested that members should notify the Secretary immediately they have obtained an appointment.

In submitting names of candidates to prospective employers it is understood that the Institution accepts no responsibility and gives no guarantee.

Library.—The Institution's Library may be consulted between the hours of 9.30 a.m. and 5 p.m. daily. (Saturdays, 9.30 a.m. to 12 noon.)

GENERAL MEETINGS.

General Meetings of the Institution will be held on the second Tuesday in each month at 5.30 p.m. at the Royal Society of Arts, John Street, Adelphi, London, W.C. 2.

Tea, coffee and light refreshments will be provided at 5 p.m. prior to each meeting.

Members may introduce visitors.

May 14th. **"Drilling Muds."**
P. Evans, F.G.S., A.M.Inst.P.T., and A. Reid, A.M.Inst.P.T.

SUMMER MEETING AND ANNUAL DINNER.

IMPORTANT CHANGE OF DATE.

The Summer Meeting and Annual Dinner of the Institution will be held in London on **Friday, 21st June,** 1935, and not on 28th June as previously announced.

Further details of the Summer Meeting and the Annual Dinner will be circulated during May.

INFORMAL DINNERS.

An informal Dinner is held at Gatti's Restaurant, King William Street, Strand, W.C. 2, immediately following each General Meeting of the Institution, to entertain the authors of Papers.

A cordial invitation is extended to all Members of the Institution.

The cost of the Dinner is 5*s*. (exclusive of wines). No separate notification of these Dinners will be issued.

STUDENTS SECTION.

(London Branch.)

Meetings of the Students Section (London Branch), unless otherwise notified, will be held at the Institution offices at 6.15 p.m. on the dates specified below.

May 7th. **"Crooked Holes."**
A. J. Haworth (Student).

May 21st. To be announced later.

Tea and light refreshments will be provided at 5.30 p.m. prior to each meeting.

The Committee of the Students Section extends a cordial welcome to all Members of the Institution to attend the meetings of this Section.

OFFICES OF THE INSTITUTION.

The Offices of the Institution will be closed on Monday, 6th May (Bank Holiday).

Commencing on Wednesday 1st May the Institution's Offices and Library will be open from 9.30 a.m. to 5 p.m. until the end of September.

NEW MEMBERS.

The following have been elected or transferred, subject to confirmation in accordance with By-Laws, Sect. IV, paras. 14–15, since the last issue of the *Journal*.

Members.

DINTILHAC, Jean Georges ... ... Paris.
ROGERS, Lewis William ... ... Richmond.

Associate Members.

COLE, Robert Leslie ... ... London.
SMITH, David Livingstone Ramsay ... ... Nottingham.
WILSON, Frank William ... ... Persia.

Transfer to Associate Members.

ROBERTS, Lawrence George Melville ... ... London.

Associate.

BARBER, Geoffrey Eric ... ... London.

NOMINATIONS FOR MEMBERSHIP.

The following nominations for membership of the Institution of Petroleum Technologists were approved by the Council on 9th April, 1935, and the application forms may be seen at the offices of the Institution.

The names of the Proposer and Seconder are given in parentheses.

As Members.

BAYLE, Pierre, Electrical Prospection, Paramount Hotel, San Fernando, Trinidad, B.W.I. (H. W. Reid; G. H. Scott.)

DAVIDSON, George, Chemist, Arend Petroleum Mij, Orangestad, Aruba, N.W.I. (R. M. Beesley; E. L. Herbert.)

EVANS, Charles Emlyn, Chemist, 28, Langthorne Crescent, Grays, Essex. (A. C. Adams; T. C. J. Burgess.)

KREULEN, Dirk Jan Willam, University Lecturer, Leede 20, Rotterdam (Z), Holland. (H. I. Waterman; W. J. Hessels.)

WALTON, Joseph Gilbert, Chemist, Anglo-Ecuadorian Oilfields, Ltd., Casilla 410, Guayquil, Ecuador. (C. Barrington Brown; L. W. Berry.)

As Transfer to Members.

GREY, Noel William, Superintendent, Compania Petrolera Lobitos, Peru. (J. W. Burford; G. C. Mclaran.)

SOLE, Ernest John, Gas Engineer, Soc. Unirea, Moreni, Prahova, Rumania. (J. E. Treacy; F. W. Penny.)

As Associate Member.

LEE, Hubert William Henry, Chemist, Union Petroleum Corporation (Pty.), Ltd., Laboratory, Maitland, Cape Town, S. Africa. (W. P. Hirst; W. H. W. Higham.)

As Student.

POORTEN, Arie Christiaan ter, Student, Bronovolaan 18, The Hague, Holland. (H. I. Waterman.)

APPLICATION FORMS FOR ADMISSION.

The Council desire to direct the attention of members who Propose or Second an Application Form for membership of the Institution to the importance of sending a covering letter for the guidance of the Election Committee.

BACK NUMBERS OF JOURNAL.

The Institution is desirous of purchasing a limited number of clean copies of Journal No. 19, April 1919, and No. 66, February 1928.

The price which will be paid for such copies is 7*s.* 6*d.*, and all inquiries should be sent to the Secretary.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. H. J. W. BRADDICK has left for Persia.
Mr. J. W. BURFORD is returning from Lobitos.
Mr. A. E. O. COOKE is leaving for Trinidad.
Mr. W. N. FOSTER is home from Trinidad.
Mr. G. T. NOTLEY is now in Sarawak.
Mr. J. H. PATTINSON has left for Persia.
Mr. M. J. ROBERTSON is returning home from Uganda.
Mr. R. K. VAN SICKLE is now in Austria.

The Secretary would be glad to learn of the addresses of the following members: J. M. BROWN, M. JAWAD JAFAR, J. CECIL JONES, E. L. LEITES, P. B. M. LINTON, A. MACLEAN, B. F. N. MACRORIE, W. J. REYNOLDS, W. MCKECKNIE ROBSON, and K. A. SPEARING.

ARTHUR W. EASTLAKE.
Honorary Secretary.

TRINIDAD BRANCH.

The 42nd General Meeting of the Branch was held on 27th February at the Leaseholds No. 1 Club, Pointe-a-Pierre, Trinidad.

Mr. P. H. B. Trasler, B.A., A.M.Inst.P.T., read a paper on "Notes on Gum, and Colour Stability Tests for Gasoline," which was followed by a discussion.

At the conclusion of the Meeting, the Chairman, Commander H. V. Lavington, R.N., proposed a vote of thanks to the Author and the President and members of the Leaseholds Club for the use of their room.

RUMANIAN BRANCH.

Meetings of the Rumanian Branch of the Institution were held on Friday 15th March and Friday 5th April, when the two following papers were presented by their authors :

15th March. Mr. J. Murray on "Mechanised Stores Accounts."
5th April. Mr. I. S. Rutherford, M.Inst.P.T., on "Theory and Practice in Casing Programmes."

There were very good attendances at both these meetings.

On Friday 3rd May Mr. Cazimir, Director of the Geological Institute of Rumania, will present a paper on "The Geology of the Rumanian Petroliferous Areas."

STUDENTS SECTION (London Branch).

On Friday 22nd March Mr. J. McConnell Sanders (Vice-President) gave a very interesting Lecture to the Students Section (London Branch) on "Health Hazards in the Petroleum Industry."

The Health Hazards discussed were those which arise solely out of the workers physical contact with petroleum or its products and by-products. Toxic substances inherent to petroleum or produced during a technical operation with it (*e.g.* sulphuretted hydrogen) were considered in relation to their possible effects on health.

The Lecture was illustrated with an interesting series of statistics of occupational diseases.

The paper concluded with some speculations regarding the trend of petroleum technology and its probable effects on the health of workers in the future.

ASSOCIATION FRANÇAISE DES TECHNICIENS DU PÉTROLE

The Institution of Petroleum Technologists extends its cordial greetings and best wishes for the success of the recently inaugurated *Association Française des Techniciens du Pétrole*.

The *Association* has developed from a small group of *Techniciens du Pétrole* formed in 1929, and has at present a membership of about 200. The Objects of the *Association* are very similar to those of the Institution of Petroleum Technologists: (*a*) to study questions of general interest relating to petroleum technology; (*b*) to supervise the observance of standards of professional conduct; and (*c*) to provide or subscribe towards places of instruction.

The first officers of the *Association* are as follows:

Hon. President: Col. LOUIS PINEAU (Hon.M.Inst.P.T.).
President: M. CH. BIHOREAU (M.Inst.P.T.).
Vice-Presidents: M. A. DE BOULARD, M. A. PELLISSIER.
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General Secretary: M. J. FILHOL.
Members of Committee: MM. H. DE CIZANCOURT (M.Inst.P.T.), J. KAPLAN, S. SHEER and P. WOOG.

At the inaugural meetings held in Paris on 22nd and 23rd March, 1935, five sections of the *Association* were formed, each having its own President:

Physico-Chimie et Raffinage (*President:* M. H. WEISS).
Géologie et Forage.
Matériel et Construction.
Technique de l'utilisation des produits dérivés du pétrole.
Economie et Statistique du Pétrole (*President:* M. J. FILHOL).

The registered address of the *Association* is at 44, Rue de Rennes, Paris 6e. The temporary address is 85, Boulevard du Montparnasse, Paris 6e.

The inauguration of the *Association* was celebrated by a banquet held jointly with the *Association Amicale des Ingenieurs diplomés de l'École Nationale Supérieure du Pétrole et des Combustibles liquides*, over which M. HENRI ROY, Minister for Public Works, presided on Saturday, 23rd March. Col. L. PINEAU referred in his speech to the encouragement afforded to the *Association* by the success of the Institution of Petroleum Technologists.

A cordial invitation is extended to the members of the Institution of Petroleum Technologists to visit the offices of the *Association*.

CONTENTS OF MAY JOURNAL.

The following Papers will be included in the May issue of the *Journal*:

Reports on the Progress of Naphthology, 1934.

NOTES ON THE PETROLEUM GEOLOGY OF WESTERN CANADA.*

By A. J. Goodman, B.Sc., Ph.D. (Associate Member).

I. The Canadian Cordillera.

(a) *General Stratigraphy.*

Proterozoic and Early Palæozoic Rocks.—According to R. A. Daly, the Canadian Cordilleran region has been divided into two broad belts since Pre-Cambrian times, and this early division is now marked by the Basement-Complex rocks of the Shuswap Terrane in British Columbia [1] (Plate No. 1). This conclusion is disputed by Schofield,[2] who quotes evidence to show that the Shuswap rocks cannot be regarded as Archæan. For the purpose of this paper this question is not of major importance, although its correct solution is fundamental for the interpretation of Cordilleran geological history. In the present investigation the most important item in this connection is the thickness of Proterozoic and Palæozoic rocks which were deposited in the earliest Rocky Mountain Geosyncline.

In the Selkirks, Purcells, and their continuation to the south a thickness of 37,000 ft. of Proterozoic sandstones, shales, and siliceous dolomites has been estimated.[3] In the western Rocky Mountains, Allan [4] reports about 18,500 ft. of Cambrian rocks, and Walcott [5] mentions more than 11,000 ft. of sandstones, silts, and limestones of Cambrian age on the eastern side of the range. Ordovician and Silurian rocks from the western Rockies are approximately 10,000 ft. thick,[4] and Walcott [6] mentions 2100 ft. of equivalent rocks on the eastern side. Ordovician and Silurian rocks are also reported from the Commonwealth Milk River No. 1, Moose Oils, and some Saskatchewan wells, but the full thickness of these rocks beneath the Plains has not yet been ascertained. They also occur on the western edge of the Canadian Shield,[7] and together with Cambrian rocks are present in the Mackenzie River Region of the North-West Territories.[10]

Devonian Rocks.—Devonian and younger rocks have been denuded from areas west of the Rocky Mountain Divide, but it appears probable that both Devonian and Carboniferous rocks once extended far to the west, for small outliers have been discovered by both Daly [79, pp. 111, 113] and Schofield.[33] At Banff about 3000 ft. of Devonian rocks are exposed with massive dolomitic limestones in the top third and thinner bedded members below.[8] These Devonian Limestones extend beneath the Great Plains lying to the east of the Rockies and outcrop along the western edge of the Shield, where, in Manitoba, they are 375 ft. thick.[7, p. 24] On Great Slave Lake about 1100 ft. of Middle Devonian Limestones are overlain by nearly 1000 ft. of Upper Devonian Limestones and shales.[9] In the Norman area Devonian shales of undetermined thickness are overlain by 400 ft. of Middle Devonian

* Paper presented for discussion at the One Hundred and Sixty-third Meeting of the Institution of Petroleum Technologists, February 12th, 1935.

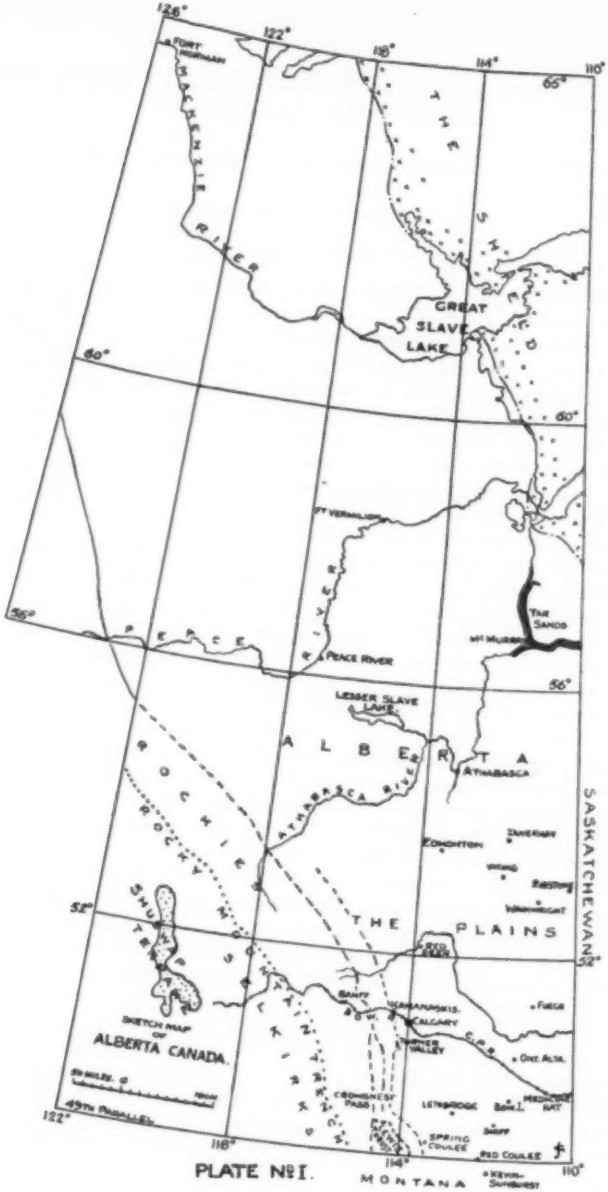

126°
122°
118°
114°
110°
65°
60°
56°
52°
MACKENZIE RIVER
GREAT SLAVE LAKE
ATHABASCA
PEACE RIVER
LESSER SLAVE LAKE
ROCKY MOUNTAINS
THE PLAINS
SASKATCHEWAN
EDMONTON
CALGARY
LETHBRIDGE
SKETCH MAP OF ALBERTA CANADA.
MONTANA

PLATE No I.

bituminous limestones, 1000–1500 ft. of Upper Devonian bituminous shales, and more than 1600 ft. of sandstones and shales.[10]

Carboniferous Rocks.—At Banff 1400 ft. of Mississippian calcareous shales are overlain by 2400 ft. of massive cherty limestones, capped by an additional 700 ft. of siliceous dolomites and quartzites, believed to be Pennsylvanian.[8, p. 11] The division between the Mississippian and the Pennsylvanian is uncertain, but the latter is not believed to extend to the east of the Foothills. Assuming the absence of Pennsylvanian rocks beneath Turner Valley (Plate No. 1), the Mississippian is approximately 2140 ft. thick as measured in the McLeod No. 4 well; the top 1500 ft. are massive (Rundle Formation), and the rest thinner bedded (Banff Shales). These are drilled thicknesses. Beneath the Plains the Carboniferous thins out, and disappears north and east of a line drawn tentatively from the Foothills eastwards through the Duvernay well, and then approximately along the Saskatchewan boundary (Plate No. 1). Upwarping progressing from east to west at the end of Palæozoic times prevented deposition of Carboniferous beds, and caused erosion to the north and east of this line.

Triassic Rocks.—Triassic rocks occur along a narrow belt in the Rockies, and 3400 ft. of dolomitic limestones and shales are reported from Banff.[8, p. 11] These rocks do not extend beyond the mountains on the east, and presumably have suffered erosion to the west.[3, p. 465]

Jurassic Rocks.—The Sierra Nevada were elevated at the close of Jurassic times,[3, p. 511] and contemporaries of these mountains arose on the present site of the Purcells and Selkirks.[33] It is therefore probable that late Jurassic sediments were not deposited west of the site of the present Rocky Mountains. From the Crowsnest area Mackay reports 3000 ft. of Jurassic shales,[17] decreasing rapidly in thickness to the east, being only 150 ft. thick beneath Turner Valley. In the Plains the thickness revealed in borings varies considerably, and is indicative of pre-Jurassic folding in Southern Alberta, as suggested by Moore from other evidence.[18, p. 1154] Jurassic rocks have been identified from wells in Southern Saskatchewan and Manitoba, but it is doubtful if they outcrop on the borders of the Shield. No Jurassic rocks are known from the Wainwright wells, and the northerly edge of these rocks is presumed to run from just south of this locality westwards towards the mountains. North of this line the Lower Cretaceous rests unconformably upon the eroded surface of the Carboniferous, and still more to the north on a similarly affected Devonian surface.

Cretaceous Rocks.—The Cretaceous rocks were apparently derived from the erosion materials of the Jurasside Mountains in the west, and were deposited in a new depression formed on the eastern part of the old geosyncline (Plate No. 2). In the Crowsnest area Mackay reports nearly 10,000 ft. of non-marine sandstones and shales of the Lower Cretaceous with coal seams.[17, p. 46] In the Bow River Valley Rutherford estimates 3400 ft. of marine Upper Cretaceous shales (Benton).[20, pp. 24, 29] From the Foothills of Northern Alberta as much as 11,000 ft. of non-marine Upper Cretaceous sandstones and shales are reported of younger age than the correlatives of the Benton Shales.[21] It appears reasonable to assume that at least 20,000 ft. of Cretaceous sediments were deposited in the deepest part of the younger Rocky Mountain Geosyncline, and possibly more.

In the Plains, Cretaceous beds are much thinner, amounting to about

W
E
SELKIRKS
ROCKY MOUNTAINS
FOOTHILLS
PLAINS
EDMONTON & BELLY RIVER
BENTON
CRETACEOUS & MONTANA
JURASSIC
TRIAS
CARBONIFEROUS
DEVONIAN
CAMBRIAN
SILURIAN & ORDOVICIAN
PRE-CAMBRIAN SEDIMENTS
ARCHAEAN
CANADIAN SHIELD
DIAGRAMMATIC SKETCH OF
THE ROCKY MOUNTAINS
GEOSYNCLINE
BEFORE THE
MAIN LARAMIDE MOVEMENTS
HORIZONTAL SCALE 1" = 20 MILES APPROX
VERTICAL SCALE 1" = 4 MILES
PLATE No 2
CRETACEOUS
PRESENT EDGE OF SHIELD
SCALE VERT. & HORIZONTAL 1" = 100 MILES APPROX

3000 ft. at Medicine Hat, and 1700 ft. on the edge of the Shield in Manitoba.[7, p. 28] The alternations of marine and non-marine conditions in these beds have been described and illustrated by Irwin.[22]

On Plate No. 2 an attempt has been made to represent the profile of the later Rocky Mountain Geosyncline. In the absence of direct evidence the width has been shown as 1·6 times that of the present Rocky Mountains. This figure was given in a hypothesis by Jeffreys.[23]

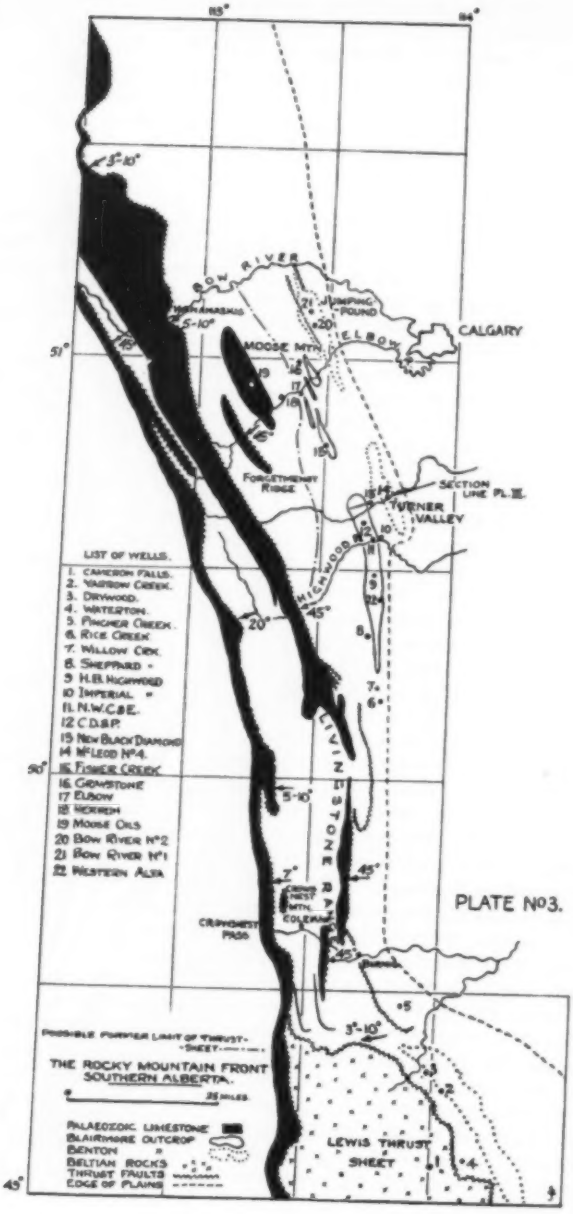
(b) *Orogenesis.*

At the end of Cretaceous times the whole of the Cordilleran Region was compressed by the forces of the Laramide Revolution. Argand [24] regards these movements (Plis de Fond) as deeper and stronger than those which affected the more plastic geosynclinal strata of the Alpine Orogenies (Plis de Couverture), and that not only were the reinforced and worn-down stumps of the Jurasside Mountains affected, but also the basement rocks of the Shield itself. Collet in a traverse along the Athabasca River found "dry overthrusts" as defined by Argand, and confirmed the latter's views.[30]

Kober's conception of the building of the American Cordillera implies the moving together of the two forelands, the Canadian Shield on the east, and the bed of the Pacific on the west.[25] He does not, however, take into account the mountains built previously to the Laramide Revolution. Accepting the general principles laid down by Kober, the Author suggests that the worn-down stumps of the Jurasside Mountains in the Laramide compression acted as a buttress, but were not sufficiently rigid to resist some distortion in themselves. This implies conditions analogous to those in Europe, where the Hercynian and other early folds have acted as resistant masses to subsequent Alpine Folding.

The writer believes that the Rocky Mountains ultimately assumed a wedge-shaped profile after being compressed between the Shield and the Jurasside buttress on the west. Plate No. 4 B illustrates a section by Raymond and Willard [26] interpreted by the writer according to Chamberlin's "Wedge Theory." [27, 29] From experimental work and field studies Chamberlin postulates that such a wedge grows by the addition of low-angle overthrusts on its outer borders. As new thrusts develop in this way the former gently dipping fault planes are turned to steeper angles as they undergo further compression in the interior of the range, and in this way the fan section is formed. For the explanation of the inner faults and their steep dips the writer prefers an interpretation based upon Cadell's classical researches, from which he concluded that a horizontal thrust surface often bends downwards and passes into a fold at depth.[28]

Raymond and Willard mention that as some of these Rocky Mountain thrust faults are followed along the strike they pass into folds. From this it is reasonable to suppose that the steeper thrust faults in the interior of the range are the deeper parts of faults revealed by the erosion of the horizontal part of the thrust sheet. This is further supported by the occurrence of the oldest rocks in the core of the range in a gently folded condition. Presumably they were beneath the zone of faulting when the mountains were formed, and have since been revealed by uplift and erosion. The faults in these oldest rocks, which are illustrated on the section, are tensional dislocations.


115°
114°
5°-10°
BOW RIVER
HIGH RIVER
5-10°
JUMPING POUND
CALGARY
ELBOW
MOOSE MTN.
51°
FORGETHEWHY RIDGE
SECTION LINE PL. III.
TURNER VALLEY
HIGHWOOD
LIST OF WELLS.
1. CAMERON FALLS.
2. YARROW CREEK.
3. DRYWOOD.
4. WATERTON.
5. PINCHER CREEK.
6. RICE CREEK.
7. WILLOW CRK.
8. SHEPPARD "
9. H.B. HIGHWOOD
10. IMPERIAL "
11. N.W.C.&E.
12. C.D.&P.
13. NEW BLACK DIAMOND
14. McLEOD No 4.
15. FISHER CREEK.
16. GRANSTONE
17. ELBOW
18. HICKMAN
19. MOOSE OILS.
20. BOW RIVER No 2
21. BOW RIVER No 1
22. WESTERN ALTA.
50°
LIVINGSTONE RANGE
CROWSNEST PASS
PLATE No 3.
POSSIBLE FURTHER LIMIT OF THRUST-SHEET
THE ROCKY MOUNTAIN FRONT SOUTHERN ALBERTA.
25 MILES.
PALAEOZOIC LIMESTONE
BLAIRMORE OUTCROP
BENTON "
BELTIAN ROCKS
THRUST FAULTS
EDGE OF PLAINS
LEWIS THRUST SHEET
49°

On Plate No. 3 further supporting evidence is illustrated. At the Crowsnest Pass Palæozoic Limestones are thrust on to Mesozoic rocks along a low-angle fault. Along the strike to the north this fault block takes the second rank inside the mountains, and the northwards extension of the Livingstone Range fault block becomes the border overthrust of the main range, where it crosses the Bow River. At this point this border thrust has a low angle of dip, but the next thrust to the west, already mentioned, is dipping steeply. In the writer's opinion the flatter part of the latter thrust block has been removed by erosion. Passing south again along the Livingstone Range, the overthrusting decreases, and folding is in increasing evidence, while the dips of the thrust faults become steeper. Apparently these are the outcrop effects which Cadell shows in cross-section. Later it will be shown that similar evidence points to like conditions beneath Turner Valley.

2. The Foothills—Southern Alberta.

(a) *Petrography of Index Horizons.*

Before considering the general interpretation of Foothills structures it is necessary to examine the detailed structure of the Turner Valley anticlinal unit, an area in which drilling has provided more information than elsewhere. This structural interpretation is based on the correlation of stratigraphical and petrographical data. A tabular arrangement of the main facts of the stratigraphical sequence is given on Plate No. 5, and, to avoid repetition of published information as much as possible, the reader is referred to the Summary Reports (Part B) of the Geological Survey of Canada from 1926 onwards for further details. The examination of the chief index horizons in thin sections is intended to supplement the information obtained by more empirical methods, which were imposed by the necessity for prompt determinations owing to the rapidity with which drilling operations progressed in 1929 and 1930. In some cases the information obtained from thin sections has led to different conclusions from those previously held.

The Bearpaw Sandstone.—No evidence of Bearpaw beds has been found in Turner Valley well samples, but a few slides were made from a sandy horizon from the Keho well from the Plains for comparison purposes. The most noticeable characteristic is the abundance of glauconite. The quartz grains are sub-angular and well graded. A few grains of orthoclase were noted, but in general felspars are very scarce. Pyrites is present, but not abundant. The cement is mainly argillaceous, and there is comparatively little calcareous matter present.

Belly River Rocks.—In the harder sandstones detrital quartz is subordinate to other clastic materials in the samples examined. It is not well graded, and angular to sub-angular outlines are usual. Re-growth by secondary silica is responsible for the angularity in some cases. Cryptocrystalline cherty material predominates. Frequently occurring felspars are at various stages of decomposition, and indicate that alteration took place before consolidation of the rock. The plagioclases are at the albite end of the series. Orthoclase fragments are noted, and occasional grains of microcline occur. Chloritic decomposition materials, muscovite and

biotite are also common. The cementing materials are frequently calcareous, but siliceous cement is common, and also argillaceous matter.

The felspars of the Blairmore appear fresher than those of the Belly River, and the cement of the former is more frequently siliceous, but except for the occurrence of maroon-coloured shales in the Blairmore, there appears nothing definite to distinguish the two formations in isolated well samples.

Beneath the Belly River beds are dark grey laminated marine shales of the Benton Formation. These contain occasional ironstone nodules, calcite veins and pyrites, with some bentonite beds.[74]

The Cardium Sandstone.—Cardium pauperculum occurs in some exposures, but is not common. Three *Cardium* bands are present in some areas, but in Turner Valley the presence of more than one band can be traced in most cases to overfolding or faulting. About 200 ft. above the *Cardium* bed and 150 ft. below it there are two thin beds of chert pebbles less than a quarter of an inch in diameter. The *Cardium* bed itself averages about 70 ft. in thickness in Turner Valley. The grade size of the quartz grains in the samples examined is fairly regular, and averages 0·08 mm. diameter. Re-growth by secondary silica occurs in places. Strained and cracked grains are common, and the inclusions are of the bubble type, indicating a non-metamorphic source.[11] Occasional tourmaline and biotite have been observed. Felspars are scarce, and pyrites is disseminated through the rock, but is not abundant. The cement is mainly siliceous and ferruginous.

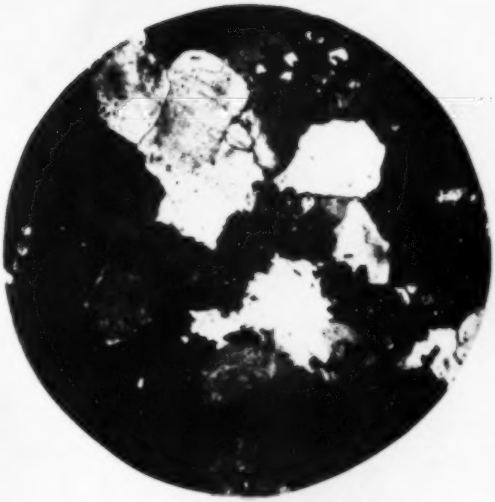
The Fish-Scale Sandstone.—In the sandy beds at the base of the Benton Shales the detrital material is mainly quartz with secondary growth of silica in many cases. Glauconite is common, and in a bed about 50 ft. above the base fish-scales are common. The quartz grains are rounded to sub-angular. Pyrites is common, but felspars are rare. Gypsum is present in small amount, and phosphate has been proved by chemical methods.

The Grit (Photo. No. 1).—Quartz occurs in angular interlocking grains in which re-growth by the addition of secondary silica can be clearly seen. There is a large amount of crypto-crystalline cherty material, and in the sections examined orthoclase occurs as 10 per cent. of the rock. Fairly fresh plagioclase fragments are at the Albite end of the series.

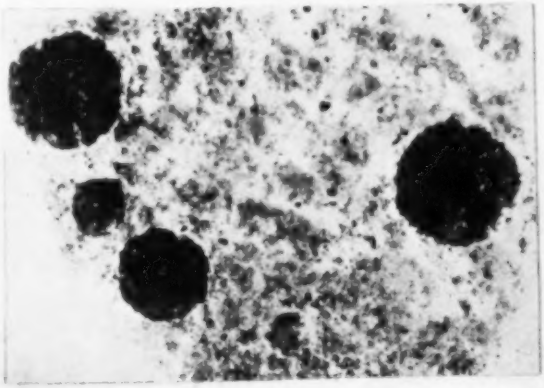
The Grit has been referred to as a "re-washed volcanic ash,"[12, p. 7] and correlated with the Crowsnest Volcanics, a tuff which occurs at about this horizon in the Crowsnest area. It is of interest to compare the two rocks.

The Crowsnest Volcanics.—For a full description of this tuff reference should be made to a memoir by Mackenzie.[13] A sample from the Drywood well is mainly composed of analcite, but the following also occur: plagioclase at the albite end of the series, sanidine, and heulandite. The matrix appears to be finely-divided analcite. Heulandite also occurs in the Dixie well at Red Coulee, where it is apparently a detrital mineral. Turner Valley is about the same distance from the Crowsnest Volcanics as is Red Coulee.

Comparisons show that the Grit has a great deal in common with the Upper Blairmore Sandstones, and there is little similarity with the Crowsnest Volcanics. The Grit is highly siliceous, the Crowsnest Volcanics the



1. THE GRIT BED.
X 45. X Nicols.

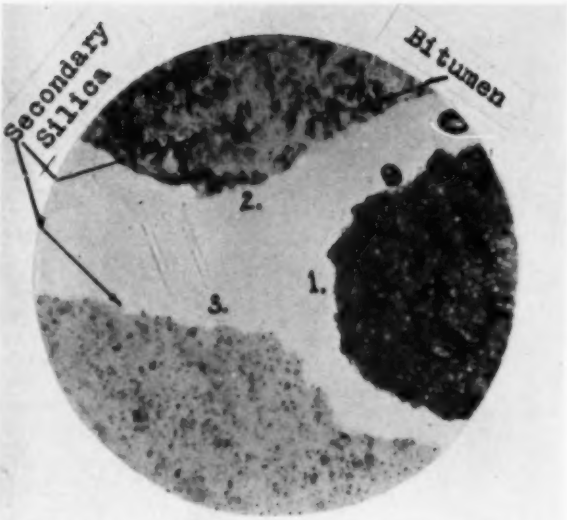


2. THE "OOLITES."
X 40 Ordinary Light.

[To face p. 228.

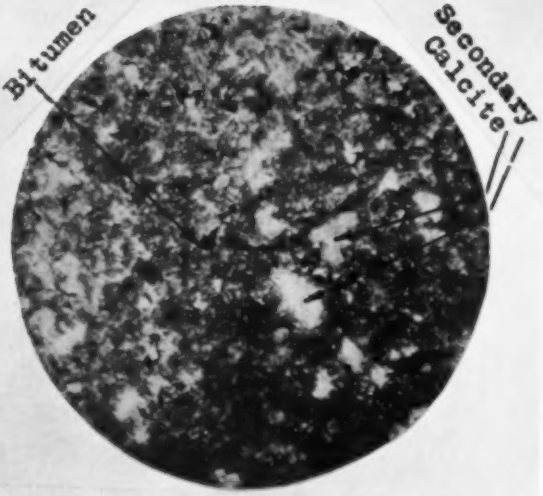
3. BITUMEN STAINED OOLITE.
Sterling Pacific 6320-30'
X 45 Ordinary Light.

4. BITUMEN STAINED "AGATE".
Spooner No.4. 5160' x 36.

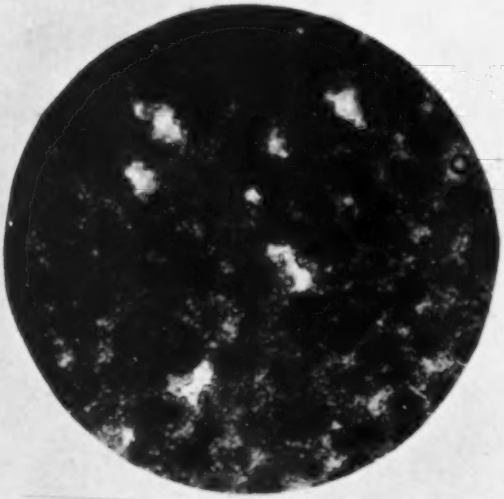


5. BITUMINOUS SILICIFIED LIMESTONE.
C.D.& P 3990' X 40.

6. BITUMEN STAINED LIMESTONE.
Sioux City 6040' x 45 Ord.L.



7. POROUS LIMESTONE.
McLeod No.4. 3780'.
x 40 Ord. L.



8. POROUS LIMESTONE.
Sioux City. 4450'.
x 40 Ord. L.

very reverse. None of the peculiar tuff minerals can be traced in the Grit, which is a coarse felspathic sandstone cemented by the infiltration of silica-bearing waters. In the Author's opinion it is not a re-washed volcanic ash, and cannot be correlated with the Crowsnest Volcanics on present evidence.

The Stockmen Sandstone.—This index horizon, which has a speckled appearance in well samples, lies 100 ft. below the top of the Blairmore Formation, which is marked by the Grit. It is a coarse to medium-grained sandstone, with abundant sub-angular, cloudy, quartz grains with bubble type inclusions. Crypto-crystalline cherty material is abundant, and calcareous matter and fresh plagioclase felspars are also present in fair amount. Chloritic decomposition products give the rock a green tint in the mass, and biotite is also present. Re-growth of the quartz grains by secondary silica was also observed.

The McDougall Segur Sandstone.—This sandstone is very similar to the Stockmen Sandstone, but appears to be slightly coarser, the grade size of the detrital quartz being up to 0·3 mm. in diameter. Plagioclase fragments are at the albite end of the series, and orthoclase is also present. Both show alteration. Coal material is also present. Various other Blairmore sandstones have been sectioned, and all show very similar characteristics.

Beneath the McDougall Sandstone there are characteristic grey and greenish sandy shales and sandstones with occasional plant remains.

The Kootenay Coal.—Owing to the adjustment of formational boundaries this coal is now placed in the Blairmore. A few thin sections of this and other coals have been prepared, but no useful comparative data are yet available.

Between the coal and the Home Sand are grey and green sandstones and shales with coal partings. There is a thin ironstone covering above the Home Sand.

The Home Sand. Type 1.—This is a strongly cemented sandstone in which detrital quartz and secondary silica are almost the only constituents. Inclusions are of the bubble type with a few acicular crystals. No calcareous matter or felspars were observed, but there are traces of pyrites. The grade size is regular, and approximates to 0·25 mm. in the samples examined, but coarser samples have been noted.

Type 2.—The detrital material is not well graded, and includes both fresh and altered felspars. Calcareous matter and chloritic decomposition products are present.

Beneath the Home Sand are grey and greenish shales with brown limey bands 40 ft. and limey sandstones 90 ft. beneath the Home Horizon.

The Fossil Bed.—Shelly bands occur in which the shell structure has been partly recrystallised. The sections indicate lamellibranchs, and the probable equivalent at outcrop contains *Unio* and *Corbula* remains. Coaly matter is also present. Dark calcareous shales and light grey calcareous sandstones lie beneath the Fossil bed.

The Oolites (Photo. No. 2).—The thin sections and micro-chemical tests show that these are sphærosiderite concretions in a fine-grained (colloidal) clay impregnated with siderite. It is probable that an iron solution has permeated a colloidal clay in which a reducing agent (carbonaceous matter) was present. The colloidal matter has adsorbed the hydrolysed iron salt;

over-saturation has resulted, and crystallisation has been initiated from a number of different centres.[14, 15, 16]

A peculiar occurrence of a similar type has been noted in a marine bed in the Wainwright Field. It occurs in the Admiral well at 2376 ft., in the Palæozoic, upon which the Lower Cretaceous non-marine beds rest unconformably. It is probable that solutions of iron salts percolated downwards from the coaly beds of the Lower Cretaceous into the underlying colloidal clays at the top of the Palæozoic.

The Dalhousie Sandstone.—This light grey calcareous sandstone contains abundant detrital felspar, up to 30 per cent. of the rock in some cases. Orthoclase, microcline, and albite type plagioclases have been noted. The detrital quartz has bubble-type inclusions, strained and cracked grains are common, and there is re-growth by deposition of secondary silica. Some fragments show quartz and felspars crystallised together on a microscopic scale (igneous rock fragments). A source in the Jurasside igneous rocks of the Selkirk region is indicated, and the basal Blairmore conglomerate of the Foothills is believed to be the equivalent of this index bed.

The Brown Sand.—The name of this bed refers to the ferruginous matter which, together with some secondary silica, forms the cement. In the samples examined the quartz grains are well graded, and average 0·12 mm. in diameter. Felspars were not observed, but there is a considerable amount of micaceous material and coaly matter. In the bubbles included in the quartz some excellent examples of Brownian Movement were observed.

The Fernie Glauconite.—This is a shaley bed with fine detrital quartz and abundant glauconite. Black pyritic shales with occasional brown limey bands occur between this Index Horizon and the Belemnites.

The Belemnites.—Sections of Belemnites guards occur in a fine-grained calcareous matrix with calcite veining. Recrystallisation has destroyed much of the radial structures in the guards, and most of the interiors are filled with pale glauconite.

The Belemnites Conglomerate.—Rounded and sub-angular quartz grains are set in a calcareous matrix. Felspars are very scarce. Numerous phosphatic nodules, which were confirmed by chemical tests, give the rock in the hand specimen the appearance of a fine-grained conglomerate.

The Fernie beds, both in the Canyon Creek exposures and in the well samples, were carefully examined for traces of secondary silicification related to that found at the top of the Palæozoic Limestone, but none could be discovered, except a doubtful small re-growth of a quartz grain in the Belemnites Conglomerate.

(b) *The Palæozoic Limestone.* (Plate No. 6.)

Several hundreds of sections have been prepared from suitable samples from the Sioux City, and from several other wells, and sixty-eight samples, from the Sioux City well only, have been analysed chemically. The calcium, magnesium, and silica have been plotted in a cumulative way, and the Dolomite Line connects points obtained by plotting the calcium value required to give a true dolomite for each particular magnesium value. The nearer the Dolomite Line approaches the black magnesium area the more complete is the possible dolomitisation for that particular sample, although

the presence of magnesium does not mean that the double carbonate is necessarily present in all cases. In the Altered Zone the chart shows that dolomitisation is almost complete at several horizons, but beneath this zone magnesium values are for the most part low.

From the examination of the Palæozoic Limestones at outcrop, dolomitisation appears to be present throughout the Devonian limestones, and also in the limestones of the Rocky Mountain Quartzite at the top of the Carboniferous. Mackay also reports some dolomitisation in the Rundle Formation underlying the Rocky Mountain Quartzite in the Crowsnest Area,[17, p. 14b] but at Banff Warren shows that these limestones are not appreciably dolomitised.[8]

From the apparent mass dolomitisation which has taken place it is believed that the formation of the double carbonate took place at the time of, or soon after, deposition of the limestone.

Throughout the Carboniferous Limestone, chert in nodules and layers is present at many horizons and over a very large area.[8, 17] The disposition of these siliceous bodies parallel to the stratification in most cases is suggestive of penecontemporaneous deposition, although subsequent replacement may have taken place locally.

With the Altered Zone at the top of the Palæozoic Limestone a somewhat different case is presented. At the end of Palæozoic times the Limestone was elevated above sea-level, and meteoric silica-bearing waters circulated in the topmost beds, replacing the calcium carbonate in preference to the dolomitised parts. With the submergence of the Limestone prior to the deposition of Jurassic beds this silicification ceased, and there is no evidence of such in the overlying Fernie Formation. The unconformable junction is marked at outcrop by a breccia, occasionally discontinuous over short distances, composed of silicified limestone and chert which can be matched with the top beds of the Palæozoic Limestone.

From the chemical analyses (Plate No. 6) it will be noted that a high degree of silicification occurs at the surface of the Limestone forming a cap or seal. The high calcium value just beneath this is shown in the thin sections to be infilling with secondary calcite (Photo. No. 7). In general the Altered Zone is distinguished from the deeper horizons by higher silica and magnesium values. Some of this silica is detrital quartz, and this has been indicated by stippling on the chart. Most of the silica, however, is shown in thin sections to be due to metasomatic replacement.

It is highly probable that during the long time the Limestone was exposed a considerable thickness of beds was removed by erosion, and the high dolomitisation of the Altered Zone was presumably not produced by sea-water acting upon the surface of the consolidated rock prior to emergence. The presence of magnesium salts in solution would cause the flocculation and deposition of colloidal silica, and it is therefore improbable that dolomitisation took place during the exposure of the Limestone as a land surface. Moreover, there are indications that dolomitisation took place prior to silicification. In the Sioux City well at 4430 ft., and at other horizons in this and other wells, typical zoned dolomite rhombs occur in a siliceous matrix which partly replaces an original calcareous ground mass. The possibilities of re-solution and dolomitisation subsequent to the general silicification have been considered, and appear, to say the least, very

improbable in these cases. In the Author's opinion the most reasonable explanation of this evidence is the orthodox one of penecontemporaneous dolomitisation, and that subsequent exposure of the Limestone resulted in the replacement of the calcium carbonate by silica.

Finally, the possibility of dolomitisation during the subsidence of the Palæozoic Limestone prior to the deposition of Jurassic beds must be considered. It is not possible to determine with certainty if the Limestone was effectively sealed by the silica replacement at its surface, but assuming the presence of gas at this time—and it will be shown later that this is highly probable—then the seal was effective in preventing the escape of the gas, and any flooding of the porous horizons was probably only partial. If conditions were suitable for dolomitisation at this time—and this cannot be taken for granted—it appears probable from the examination of the thin sections that it was subsidiary to the dolomitisation which took place prior to the general silicification. It is concluded that most of the dolomitisation was penecontemporaneous, and that the high dolomite values of the Altered Zone are due to the removal of calcium carbonate from the original rock. It is considered improbable that the Altered Zone represents the highly dolomitic lower horizons of the Rocky Mountain Quartzite, for between Turner Valley and the Banff exposures of the Rocky Mountain Quartzite the Canyon Creek exposures of the Palæozoic Limestones reveal no evidence of the presence of the Rocky Mountain Quartzite.[66, p. 41b]

The leaching of Calcium Carbonate by meteoric waters would increase the proportion of dolomite present, and in place of the calcium carbonate either voids, silica, or some other deposit would remain. In many cases the chemical analyses indicate almost a pure dolomite with little or no silica. It is probable that originally voids were present. In the Kevin-Sunburst field in Montana, Perry reports porosities of more than 60 per cent. in the Palæozoic Limestone in some cases, and porosities of this order may have been present in the Turner Valley Limestone at one time. The Author agrees with Perry [52, pp. 12-13] that, as in the case of the Kevin-Sunburst Limestone, many of these zones have probably lost their original porosity by compacting of the Limestone under the heavy overburden of Mesozoic sediments, and in the case of Foothills structures by the additional stress of mountain-building in Laramie times. The brecciated zones occurring near the top of the Palæozoic Limestone at outcrop in Canyon Creek [66, p. 42b] may well be indicative of the collapse of the more cavernous zones. The full significance of this with regard to oil and gas occurrence is discussed in a later section.

The porous reservoirs which contain the naphtha-bearing gas in Turner Valley occur at various horizons in the Altered Zone. Small amounts of gas have been reported from below this zone, but they are not important. In the samples of porous limestones examined, the diameter of the pores is in some cases as much as 1 mm., but usually less. It would appear that this size of opening was not sufficiently large to cause collapse of the rock under pressure of the overburden.

A comparison of thin sections of the gas-producing limestone in the Sioux City and McLeod No. 4 wells reveals significant information. Photograph No. 8 shows a porous limestone which yields gas from 4450 ft. in the Sioux City well. Chemical analysis shows that it is almost a pure dolomite, with

little if any silica present. In texture it is spotted (pseudo-oolitic) with pore spaces of about 0·2 mm. diameter. By careful comparison of textures in thin sections it has been possible to match the limestone sequence between the Sioux City and McLeod No. 4 wells, which are located about 250 yds. apart. The spotted dolomite occurs in the McLeod No. 4 well at 3800 ft., where it appears to be non-porous. In the latter well, however, there is a characteristic porous limestone at 3780 ft., illustrated in Photograph No. 7. The pores are small, and there has been a good deal of infilling with secondary calcite, which under crossed-nicols extinguishes over large areas as one crystal. The chemical analysis of this horizon, which occurs at 4430 ft. in the Sioux City well, shows the high calcium content clearly, and in this well the porosity has apparently been completely filled in.

The two gas horizons in these two adjacent wells are about 20 ft. apart stratigraphically. There may be some inter-communication, and there are other horizons in which slight porosity occurs, but the evidence indicates that the gas is preserved in a series of porous lenticles with limited inter-communication. Conditions such as these probably account for the independent behaviour of many closely adjacent wells in Turner Valley, and the wide range of "closed-in" pressures in different parts of the field.

Photograph No. 7 shows solid bitumen of high carbon ratio disseminated through the Limestone. This bitumen occurs at various horizons, and has been observed deep in the Devonian in the Moose well samples. It is unlikely that it is a residue from lighter hydrocarbons which have been exposed to the atmosphere, as suggested by Perry for similar bitumen revealed in wells in Montana.[53, p. 22] Similar material is associated with the brecciated zones in the Canyon Creek outcrop of the Palæozoic Limestone. This bitumen is practically insoluble in ordinary solvents, but there seems little doubt that it has a petroliferous origin, for in Photograph No. 6 the bitumen staining in the Limestone has the appearance of having once been liquid. In making the slides every precaution was taken to prevent any movement of the bitumen.

Photograph No. 4 shows "Agate" structure in secondary silica from Spooner No. 4 well at 5160 ft. The black band near the outer edge of the silica is bitumen, and bordering the silica is limestone which is also stained with bitumen. The writer suggests the following history for this specimen. Metasomatic replacement of the limestone commenced from a small detrital quartz nucleus, which was re-grown to form the central quartz crystal. Subsequent growth took place at right angles to the faces of this crystal. As replacement proceeded, iron salts (which form some of the banding) from the original limestone, and also contained bitumen, were pushed ahead of the advancing silica until conditions prevented further movement, replacement then continued on the outside of the bitumen. Some of the bitumen which was pushed ahead of the outer band of silica now occurs in the enclosing limestone.

Photograph No. 3 shows an oolite from the Sterling Pacific well at 6320–6330 ft. The coats of the oolite grains are stained with bitumen, but the matrix is comparatively free from this staining. It is suggested that the bitumen staining was contemporaneous with the formation of the Limestone.

In a sample from 3990 ft. in the C.D. and P. well (Photo. No. 5) there is

further evidence of a similar nature. The fragment has been divided into three pieces to bring it into the photographic field. No. 1 shows limestone with bitumen inclusions. No. 2 shows this same limestone almost completely replaced by secondary silica with the bitumen still remaining, and still showing the form of previously adjacent rhombs. No. 3 shows the silicified limestone after heating to remove the bitumen; a number of dolomite and calcite rhombs are still visible.

From the evidence just quoted there seems little doubt that the bitumen was present before the general silicification took place at the end of Palæozoic times.

Fluorite is a mineral which appears to be generally disseminated throughout the Limestone in small particles. Warren reports this mineral from near Banff at a higher stratigraphical horizon than occurs in the Turner Valley Palæozoics, and from its association with phosphatic matter suggests that it may be derived from fish remains.[8, p. 73] Allan reports fluorite in small amount associated with the igneous intrusion at Field, B.C.[54] In the Foothills there does not appear to be any phosphate associated with the Fluorite, and from its general disseminated occurrence hydrothermal action appears to be a probable cause, but the time of deposition is difficult to determine. In one thin section the fluorite is intercrystallised with silica, but it is not possible to decide if this indicates that it was contemporaneous with the general silicification. No fluorite has been observed in the Palæozoic Limestones from the Plains wells, nor in any of the strata overlying the Palæozoics in either the Foothills or Plains.

Anhydrite and gypsum are present in small amount at most horizons in the Palæozoic Limestone, and in comparatively thick deposits in some wells. Although probably a primary constituent of the rock deposited under lagoonal conditions, which also favoured the formation of dolomite, most of the calcium sulphate now frequently occurs as a secondary mineral, having been re-deposited. A peculiar case of replacement occurs in the C.D. and P. well at 4750 ft. The matrix of an oolitic limestone has been replaced by anhydrite, and some of the anhydrite crystals have "bitten" into the oolite grains. In one oolite grain the nucleus is the test of an *Endothyra*.

The only foraminifera found in these sections were *Endothyra* and *Ammodiscus*. These fossils are abundant in the zone shown on the chart, but a few specimens were observed at other horizons. Numerous attempts have been made to use these foraminifera and other primary characters of the Limestone for the purpose of correlating the various limestone sections penetrated by wells in the Foothills, but the evidence is not sufficiently distinctive for this purpose, although a fairly definite relationship has been established in the three Turner Valley wells shown on Plate No. 6. Secondary characters such as dolomitisation, except in the case of closely adjacent wells, cannot, of course, be used for correlation purposes.

(c) *Structural Evidence from Surface.* (Plate No. 3.)

The surface structure of the Foothills belt between the Bow River and the International Boundary is for the most part characterised by a series of imbrications in Mesozoic rocks, with thrust faults which in most cases dip steeply at outcrop. In the more northerly part two parallel belts each

show evidence of general anticlinal conditions. The easterly belt includes the Jumping Pound and Turner Valley anticlinal units, and at surface pitches down to the south, and disappears just north of the Highwood River. The other belt lies parallel to and just west of the first, and pitches southwards between the Livingstone Range and the Plains. In the south, to the east of the Lewis thrust sheet, the Foothills reveal first a gentle anticlinal fold (enclosed by a dotted line on Plate No. 3), followed by an easterly border of strongly disturbed and imbricated rocks. To the north, Moose Mountain is apparently a normal hogback of Palæozoic Limestone, which on its easterly flank shows no evidence of intense disturbance of the usual Foothills type for a distance of seven or eight miles. To the south-west of Moose Mountain is another Palæozoic inlier, with a thrust fault on its easterly border dipping to the west at about 45°.

(d) *Structural Evidence from Turner Valley Wells.*

The very large amount of information which had been accumulated, mainly by the efforts of colleagues in the laboratory of the Supervisory Mining Engineer's department at Calgary, together with information subsequently published by the Provincial authorities, has been used to prepare a series of cross-sections through the Turner Valley anticlinal unit on the scale of 1 in. to 500 ft., and a contour map on the Palæozoic Limestone surface on the scale of 4 in. to the mile. The method adopted was to draw sections in every direction connecting up the various wells, and to coordinate these as far as possible in three dimensions. The correlation of these details was a task which occupied several months, but in this paper it is only possible to give a mere outline in description and diagram of the final conclusions. Many of the wells deviate from the vertical. Information was available concerning the amount of deviation in nineteen wells, and directional information was known to the Author in only one of them. Concerning the latter, confirmation of its reliability is lacking. From many of the wells there is no information concerning straightness or otherwise. The opinion has been expressed that such conditions vitiate the whole of the sub-surface evidence.[34 disc.] However, by comparison between adjacent wells it is evident that the relative positions and repetitions of the various Index Horizons can give general indications of the manner in which the rocks have yielded to stress, and on the small scale adopted any distortion is almost negligible.* There is, however, no intention of assuming a precision which does not exist, and to prevent misunderstandings in this respect the contour map on the Limestone surface has been omitted.

After careful examination and comparison of the evidence it is the writer's considered opinion that with the wells available, even if they were all straight, it would still be impossible to represent the surface of the Limestone accurately. Moreover, owing to the independent movement of the Mesozoic Formations, it is not possible to use any of the subsidiary

* Since this paper was written, Dr. T. A. Link has forwarded to the writer a copy of his structure contour map of the Turner Valley Limestone, on which some corrections for deviation have been made. In only two or three wells is it possible to detect any difference between the Limestone contacts as interpreted by Dr. Link and as interpreted by the writer. Deviation effects on small-scale diagrams appear to be negligible.

surface structures to supplement the well data for the interpretation of structural conditions in the Limestone. It has been suggested that the structure of the Limestone beneath Turner Valley should be interpreted according to the "Regional Habit," *i.e.* on the same general lines as the structures observed in the Limestone outcrops more to the west. Whilst recognising the value of such observations, it should be remembered that the outcropping limestones have probably yielded to compressive stress for a longer period and under different conditions of overburden than the deeper buried limestones on the extreme easterly edge of the Foothills. In the more westerly limestone outcrops more intense subsidiary structures are to be expected.

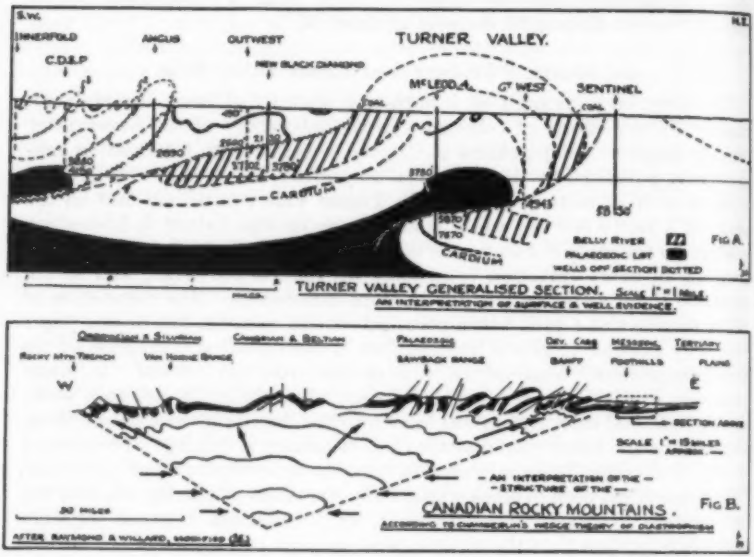


PLATE No4.

On Plate No. 4, Fig. A, is shown a general profile representing the writer's conclusions concerning the type of structure developed in Turner Valley.

In the extreme northerly end of the Field the well evidence on sections 1, 2, and 3, Plate No. 8, indicates that the Palæozoic Limestone lies very deep, and that, as suggested previously,[34] the Benton and Blairmore formations have moved forward along a thrust surface independently of the Limestone. From the interpretation of well sections in proximity to Section No. 4, the front of the Limestone thrust sheet appears to be striking more to the west in Sections 3 and 4. Strong over-folding or over-thrusting is also indicated by the repetition of the *Cardium Horizons* in these sections.

In the north-central part of the field the Limestone elevations in the different wells do not show the wide variations characteristic of the southern end of the field, except on the western side, where back-folding and possibly under-thrusting are indicated (Sections 7, 8 and Oblique Section, Plate

No. 9). The absence of repetitions in the beds immediately overlying the Palæozoic Limestone is in marked contrast with the many repetitions in the higher parts of the sections. In the exceptional case of the Home Sand shown on Section No. 7, Plate No. 9, the repetitions are apparently caused by the forces which produced the back-folding in the Limestone. Repetitions in the *Cardium* bed are indicative of over-folding or over-thrusting, and, as the deeper horizons are not affected in this way, it appears probable that this type of structure does not continue to depth. In the case of Section No. 8 over-thrusting is indicated in the higher horizons and an under-thrusting tendency in the Palæozoic Limestone. For this condition there must be strong independent movement in the Mesozoic formations, probably in the Benton Shales. Indications of strong attenuation of the beds lying between the *Cardium* Horizon and the Palæozoic Limestone are present in Section No. 11, Plate No. 10, and the Benton Shales have apparently been squeezed out into the crest of the surface fold. For these reasons, and because the correlation of the various *Cardium* Sandstone and Pebble Bed contacts indicate it, the thrust faults in the Benton Shales are shown as steep at outcrop and flattening out at depth. This is the type of fault profile which experimental research [31] and theoretical analysis [32] anticipate under similar conditions of stress, and wherever sufficient evidence is available to interpret structural conditions such faults appear to be characteristic of the Foothills (Plate No. 4, Fig. A, and Plate No. 11, Figs. A and B).

In the southern part of the Field, especially in the vicinity of Sections Nos. 18 and 19, Plate No. 11, there are indications that the Limestone has steep dips, and there are many repetitions in the deeper Mesozoic horizons, as well as in the Benton Shales. It is possible that the Limestone is here cut by several faults with steeper dips, replacing the flatter main fault revealed beneath the McLeod No. 4 well. In the Livingstone Range there is a decrease in the thrusting as the dips of the faults become steeper towards the south, and the Turner Valley structural unit may have similar characteristics. This may be indicative of the passing of the faulting into folding, as the general structure pitches down to the south.

From the correlation and interpretation of this well evidence the writer concludes that the higher Mesozoic beds have suffered over-thrusting and over-folding independently of the structures in the Limestone, but that the deeper Mesozoics have moved to a larger extent with the Limestone. In other parts of the Foothills, where these deeper horizons are without the support of the Limestone, they show little if any more competence than the younger Mesozoics.

The Main Thrust Fault.—The Dome No. 1 well (4F on the structure sections) passed out of Blairmore beds into Benton Shales between 5600 ft. and 5800 ft. (Section No. 5, Plate No. 8 and Oblique Section, Plate No. 9). The United No. 4 well reached the Limestone at 5880 ft., passed into inverted Fernie beds at 6055 ft., and Benton Shales were identified at 6200 ft. Chert pebbles at 6280 ft. suggest that the well was in Benton Shales near the *Cardium* Horizon when drilling was stopped at 6360 ft. The position of the front of the Limestone Thrust Sheet is determined fairly closely in this locality.

The evidence from some of the older wells on Section No. 9, Plate No. 9,

is not very full, but the Cooper Nanton well probably finished in Belly River rocks at 4830 ft., and the Great West No. 1 (9E) in the same formation at 5400 ft. The main fault has been placed at 4950 ft. approximately. This evidence is coupled with that from the British Dominions No. 1 well (11A, Section No. 11, Plate No. 10). This well apparently passed out of Benton Shales into Belly River beds at about 5440 ft., where the fault is shown. About a quarter of a mile west of the latter well Royalite No. 6 (11K, Plate No. 7) reached the Palæozoic Limestone at 4280 ft. The front of the Limestone fault block can therefore be fairly closely located at this point.

The McLeod No. 4 well, shown on Section No. 9, Plate No. 9, passed out of the Palæozoic Limestone at 5870 ft., and then penetrated an inverted, attenuated, and fragmentary sequence of Mesozoic beds in which several of the Index Horizons were recognised. The *Cardium* Sandstone was penetrated at 6090 ft., again at 7570 ft., and a third time at 7735 ft. The main fault has been placed at 5870 ft., and by connecting this point with the most easterly fault outcrop known at surface the profile on Section No. 9 was drawn.

In the southern part of the Field the Mill City well (21A, Section No. 21, Plate No. 11) reached the Benton Shales at 5010 ft., after passing through 500 ft. of Palæozoic Limestone. The Stirling Pacific well No. 1 (21D) penetrated about 1280 ft. of limestone before entering Blairmore Beds at 6436 ft. In view of the reversed succession beneath the fault in the McLeod No. 4 well, it is possible that the Mesozoic beds beneath the main fault in the two wells mentioned above, are not in their original disposition.

(e) *Structural Evidence from Other Foothills Wells.*

The numbers marked * refer to locations shown on Plate No. 3. A well drilled near Cameron Falls * 1 penetrated about 1200 ft. of Pre-Cambrian rocks before reaching the underlying Mesozoics. Correlation with the fault outcrop at surface indicates a low angle of dip for the Lewis Thrust surface.

Many wells drilled in the gentle surface structure east of the Lewis Thrust Sheet found repetitions indicating thrust faults at depth.

North of this as far as the Highwood River several wells have found repetitions, but no indications of large scale thrusting occur, nor is there any evidence of such in the Highwood River wells.

West of Turner Valley the information from the various wells is interpreted on Plate No. 4, Fig. A, in its relationship to the general surface geology mapped by the Canadian Geological Survey.

In the Cottonbelt well * 15 on Fisher Creek the drilling passed from Kootenay beds into Belly River rocks at 2680 ft., proving an over-thrust fault. The connection of this fault with the nearest outcropping fault to the east is shown diagrammatically on Plate No. 11.

An interpretation of evidence from the Bow River No. 2 well in its relation to surface evidence is illustrated diagrammatically on Plate No. 11 also.

The Moose Oils well * 19 started drilling approximately 2000 ft. below the surface of the Palæozoic Limestone, and was still in limestone (possibly Cambrian) at 2800 ft. No indications of large scale over-thrusting had been met with at this depth. The Herron well two miles to the east of Moose

Mountain penetrated nearly 900 ft. of Palæozoic Limestone without finding any evidence of thrusting.

Several wells have been drilled in the Valley of the Bow River in imbricated Mesozoic formations. No useful evidence of the disposition of the Palæozoic Limestone has been obtained except in the case of the Wabash well. The latter is situated on the northerly pitching end of the Moose Mountain anticline. After penetrating a thin cover of Blairmore, Kootenay, and Fernie beds, the Palæozoic Limestone was struck at 1480 ft., and drilling continued to 3056 ft. in this formation.

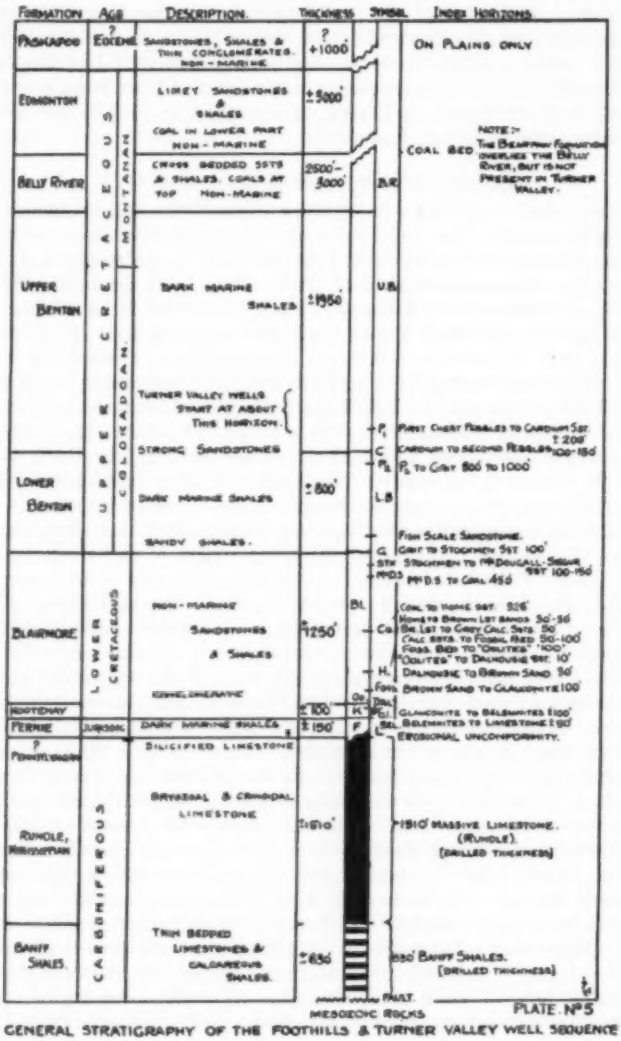
(f) *Interpretation of Foothills Structures.*

The structures of the Foothills are the records of the closing stages of the Laramide upheaval. The rocks subjected to compressive stress may with reason be assumed to consist of at least 8000 ft. of sandstones and shales of the Fernie, Kootenay, Blairmore, Belly River, and Edmonton Formations. In addition a band of Benton Shales about 3000 ft. in thickness lies with its base about 1500 ft. above the Palæozoic Limestone (Plate No. 5). The top 1500 ft. of limestone is massive, and overlies about 600 ft. of thinner bedded limestones resting on a further series of Palæozoics about which there is little information. This thick Palæozoic Limestone is obviously the most competent member of this sequence of rocks. The overlying thinly bedded sandstones and shales, and particularly the thick Benton Shales, are relatively incompetent, although the more massive Belly River sandstones appear to be more competent than associated rocks.

It is the Author's opinion that in the Foothills, as in the Mountains, the Palæozoic Limestone transmitted the greater part of the stress. In the case of Turner Valley the thrust fault developed from a preliminary fold, probably located on the site of a flexure of earlier age, and this fold broke before much overturning had taken place. Thrusting took place along the thinner bedded limestones (the Banff Shales). Except for small faults, the Belly River sandstones appear to have kept their general form as a fairly competent arch, but the Benton Shales yielded incompetently, and numerous minor over-thrusts developed. The forward movement of the Limestone was, in the writer's opinion, taken up to a large extent by deformation of the overlying beds, chiefly the Benton Shales, with the result that surface evidence of over-thrusting is comparatively insignificant to the east of the main surface fold. The information from wells on this flank shows that attenuation of Mesozoic beds is very severe, and there is a compensating increase in the normal thickness in the middle of the arch (Sections 9, 10, 11). The main fault, at first almost horizontal, became progressively steeper as resistance to forward movement increased, until it became almost vertical at outcrop. Similar conditions have been analysed by Bailey Willis,[32] and Cadell's illustrations of experiments, reproduced on Plate No. 9, Stage 1, show similar results. If compression had continued, a fault with a lower angle than the first would probably have broken through in advance of the latter, and it is probable that ultimately the Limestone would have over-ridden the surface almost horizontally. Plate No. 9, Stage 2, of Cadell's experiments illustrates the process on a small-scale model.

The writer believes that the profile of the main fault beneath Turner

Valley is not that of a large-scale over-thrust extending beneath the whole of the Foothills belt, as was at one time thought by some geologists,[37,38,39,40]



GENERAL STRATIGRAPHY OF THE FOOTHILLS & TURNER VALLEY WELL SEQUENCE

but that the shortening of the Limestone is produced by several over-thrusts of moderate displacement, a conception stated in an earlier paper.[34]

To the west of Turner Valley another similar thrust has presumably developed in the Limestone (Plate No. 4). The extent of its forward

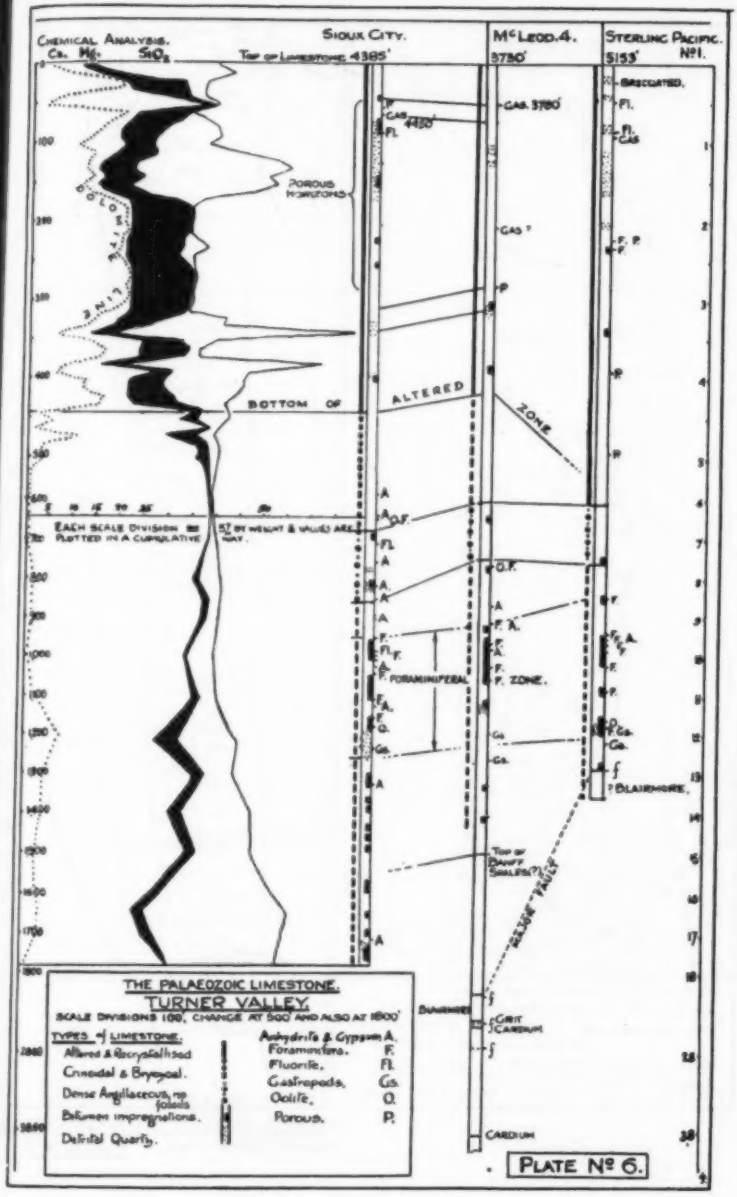
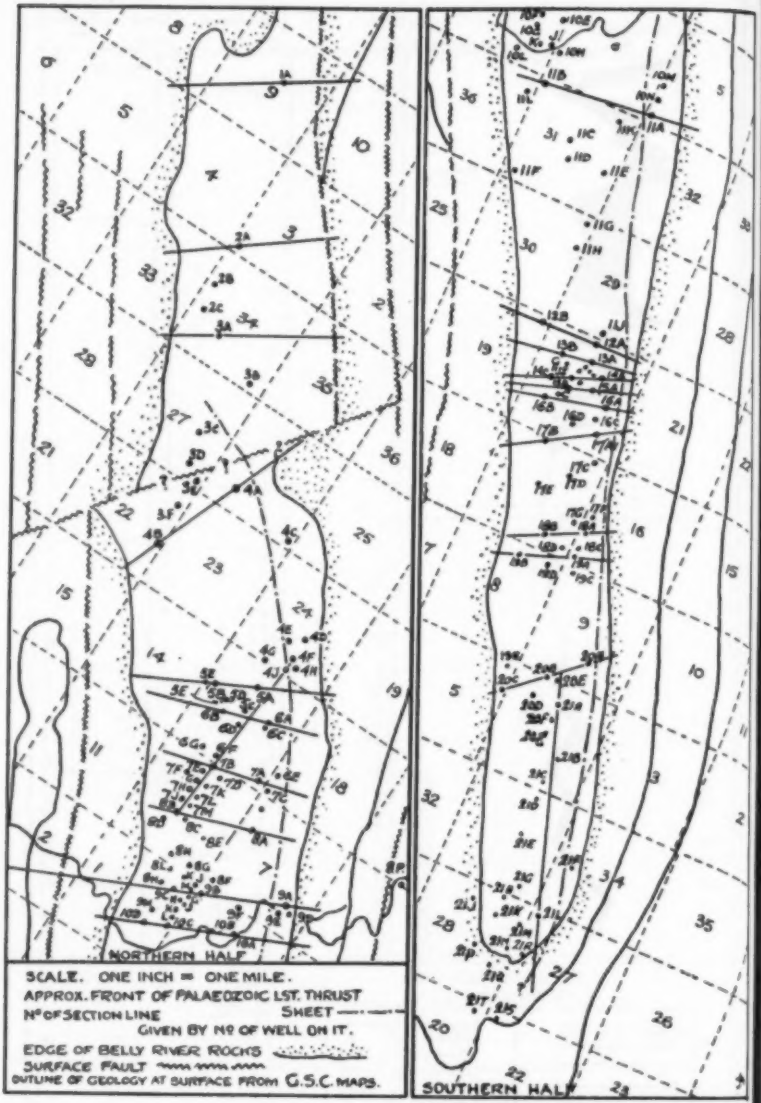
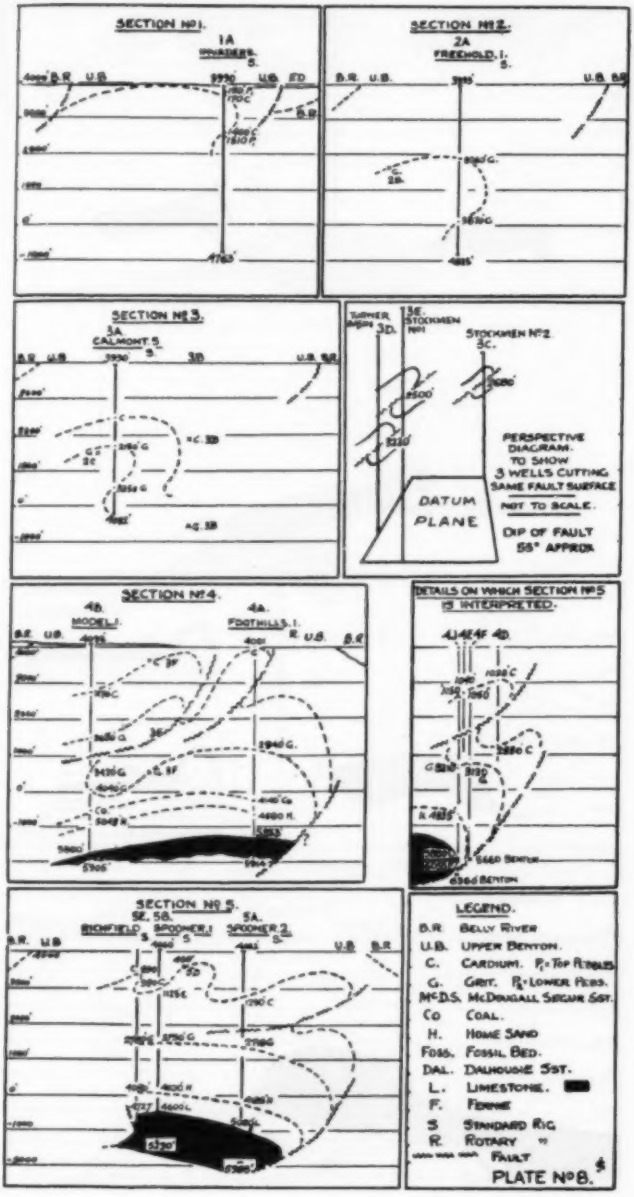
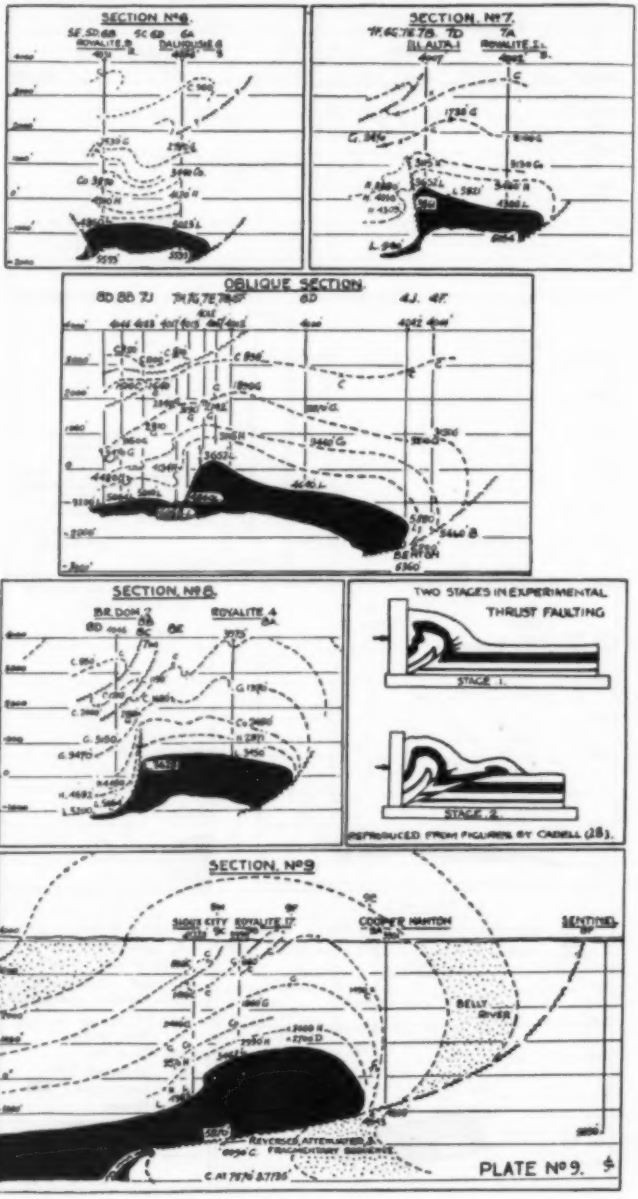

CHEMICAL ANALYSIS.
Ca. Mg. SiO2
SIOUX CITY.
TOP OF LIMESTONE 4385'
McLEOD.4.
3780'
STERLING PACIFIC.
5153'
No1.
BRECCIATED.
Fl.
GAS 3780'
GAS 4350'
POROUS HORIZONS
GAS ?
F. P.
P.
BOTTOM OF
ALTERED
ZONE
EACH SCALE DIVISION IS PLOTTED IN A CUMULATIVE
% BY WEIGHT & VALUES ARE ONLY.
O.F.
A.
F.
FORAMINIFERAL
F. ZONE.
Ga.
? BLAIRMORE.
TOP OF DRIFT SHALES(?)
FAULT
BANFF
GRIT
CARBON
CARDIUM
THE PALAEOZOIC LIMESTONE.
TURNER VALLEY.
SCALE DIVISIONS 100', CHANGE AT 500' AND ALSO AT 1800'
TYPES of LIMESTONE.
Altered & Recrystallised
Crinoidal & Bryozoal.
Dense Argillaceous, no fossils
Bituminous impregnations.
Detrital Quartz.
Anhydrite & Gypsum A.
Foraminifera. F.
Fluorite. Fl.
Gastropods. Ga.
Oolite. O.
Porous. P.

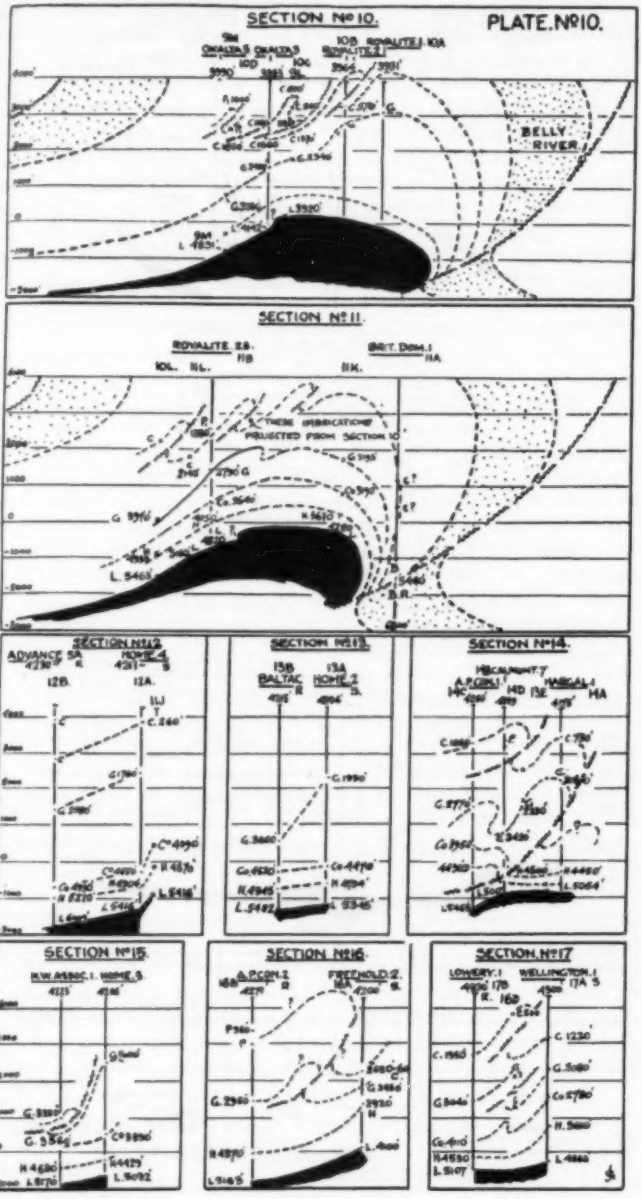
PLATE No 6.

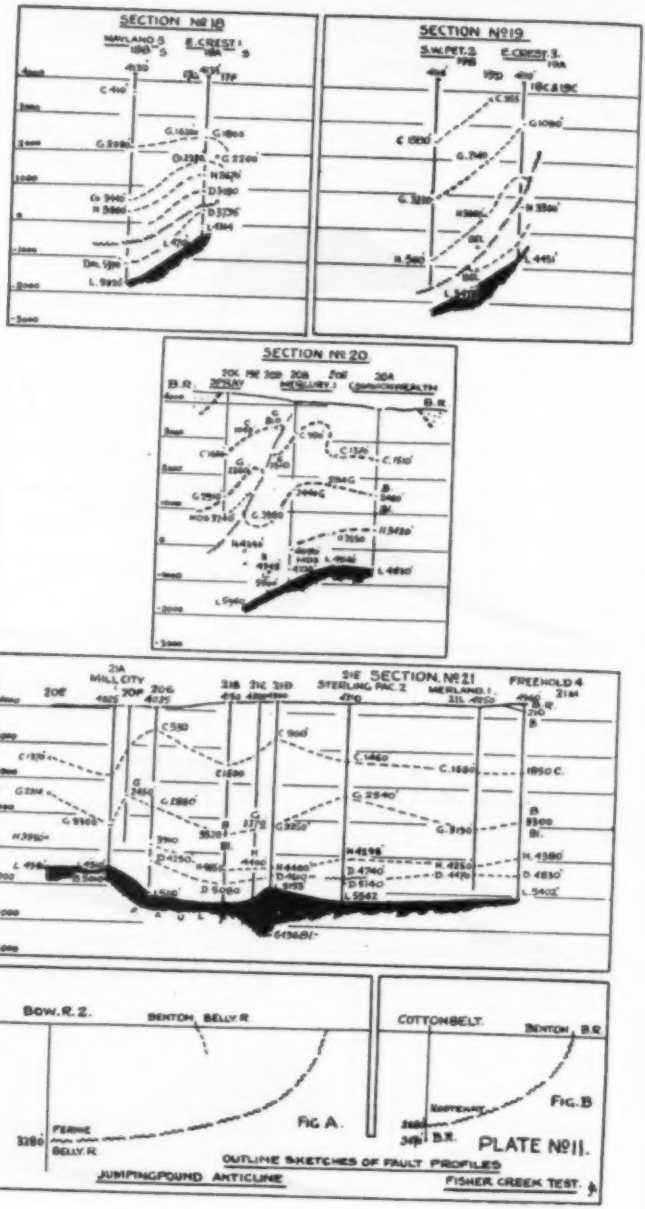

NORTHERN HALF
SOUTHERN HALF
SCALE. ONE INCH = ONE MILE.
APPROX. FRONT OF PALAEOZOIC LST. THRUST
Nº OF SECTION LINE
SHEET
GIVEN BY Nº OF WELL ON IT.
EDGE OF BELLY RIVER ROCKS
SURFACE FAULT
OUTLINE OF GEOLOGY AT SURFACE FROM G.S.C. MAPS.

TURNER VALLEY OIL & GAS FIELD.
SHOWING SECTION LINES. PLATE. Nº7.


SECTION No1.
1A
WHISKEY
S.
B.R.
U.B.
SECTION No2.
2A
FREEHOLD I.
S.
B.R.
U.B.
SECTION No3.
3A
CALMONT S.
S
3B
B.R.
U.B.
SECTION No4.
4B
MODEL I.
4A
FOOTHILLS I.
B.R.
U.B.
SECTION No5.
5B, 5C
RICHFIELD
SPOONER I.
S
5A
SPOONER 2.
S
B.R.
U.B.
3D
3E
STOCKMEN No1
STOCKMEN No2
3C
PERSPECTIVE DIAGRAM TO SHOW 3 WELLS CUTTING SAME FAULT SURFACE
NOT TO SCALE.
DIP OF FAULT 55° APPROX
DATUM PLANE
DETAILS ON WHICH SECTION No5 IS INTERPRETED.
LEGEND.
B.R. BELLY RIVER
U.B. UPPER BENTON.
C. CARDIUM. P2 TOP PEBBLES.
G. GRIT. P1 LOWER PEBS.
McD.S. McDOUGALL SEGUR SST.
Co COAL.
H. HOME SAND
Foss. FOSSIL BED.
DAL. DALHOUSIE SST.
L. LIMESTONE.
F. FERNIE
S STANDARD RIG.
R. ROTARY
FAULT
PLATE No8.


SECTION No 8.
SECTION No 7.
OBLIQUE SECTION
SECTION No 6.
TWO STAGES IN EXPERIMENTAL THRUST FAULTING
STAGE 1.
STAGE 2.
REPRODUCED FROM FIGURES BY CADELL (28).
SECTION No 9
BELLY RIVER
REVERSED, ATTENUATED & FRACTURED SURFACE
PLATE No 9.


SECTION Nº 10.
PLATE. Nº 10.
BELLY RIVER.
SECTION Nº 11.
SECTION Nº 12.
SECTION Nº 13.
SECTION Nº 14.
SECTION Nº 15.
SECTION Nº 16.
SECTION Nº 17.


SECTION Nº 18
SECTION Nº 19
SECTION Nº 20
SECTION Nº 21
BOW. R. 2.
BENTON, BELLY R.
FERNIE
BELLY R.
FIG. A.
COTTONBELT.
BENTON, B.R.
KOOTENAY
B.R.
FIG. B
OUTLINE SKETCHES OF FAULT PROFILES
JUMPINGPOUND ANTICLINE
FISHER CREEK TEST.
PLATE Nº 11.

movement cannot be determined, but it is probably greater than that of the Turner Valley thrust, for the shortening produced in the overlying Mesozoics appears more marked. In this case it appears that Cadell's second stage has been reached (Plate No. 9), and that a block of Mesozoic rocks had commenced to move along a low-angle fault in front (to the east) of the Limestone block, but from the Section on Plate No. 4 it is apparent that more than one interpretation of the evidence is possible.

There are probably other Limestone thrusts to the west of this, and it is possible that an upwarp occurs in the Limestone between Turner Valley and the C.D. and P. well, but this is mere speculation, and no evidence to support it is available. A surface fold also occurs to the north and east of Turner Valley; this may indicate the commencement of a new border structure.

Moose Mountain anticline may have been over-ridden at one time by the Palæozoic Limestone block of the main range, and the superincumbent load may have prevented any thrusting movement within the Limestone mass. This is an application of Stewart's hypothesis to explain the gently folded belt in front of the Lewis Thrust Sheet.[41]

In the case of the Lewis Thrust, which was formed comparatively late in the orogeny,[42, 43] Stewart's suggestion just referred to appears reasonable, but when friction had brought the thrust sheet to rest, deeper-seated movements probably started again in the Palæozoic rocks, with the result that the Mesozoics, held by the now stationary upper block, were sheared by the movements in the underlying support. Farther east the restraining influence of the over-burden was absent, and shortening in the Palæozoic rocks produced the usual complicated structures in the overlying incompetent Mesozoic strata.

With regard to the structural features characteristic of the Mesozoic rocks, several examples have been quoted of faults which are steep at surface, and pass downwards with a decreasing angle of dip. Bailey Willis,[32] Chamberlin and Miller,[44] and Quirke [31] have analysed and discussed similar faults produced experimentally. The Author is unable to accept the hypothesis that the Palæozoic and Mesozoic rocks react to compression as one mass, and therefore is unable to agree with the opinion that the structural features revealed at surface continue to depth, or that the surface faults pass down to the major over-thrusts at steep angles, producing a type of structure similar to the imbricate zone of the North-west Highlands of Scotland.[45] Wherever sufficient well evidence is obtainable the flat overthrust passing upwards into steeper angles is indicated. The depth at which the flatter part of the fault occurs will vary with the conditions, and in some cases it is doubtless at the surface, having been exposed by erosion. Some of the surface faults show evidence of a gentle angle of dip, and probably others would be revealed were it not for the obscuring effects which exist, although it is apparent that most of the faults have a steep dip at surface.

3. Source and Reservoir Rocks of the Oil and Gas.

(a) *General Survey.*

In the Mackenzie Basin the Devonian rocks, in particular the Fort Creek shales of the Upper Devonian, are highly bituminous, and brecciated lime-

stones lying at the top of the Silurian are also stained with bitumen.[46] The Cretaceous shales which overlie the Devonian are composed in part of fragments derived from the Fort Creek shales.[35, p. 53]

The sandy and shaley phase in the Devonian at Norman is represented on the borders of Great Slave Lake by a limestone and shale series, and here the Middle Devonian is bituminous.[9]

At McMurray the Tar sands are of Lower Cretaceous age, of non-marine origin, and rest unconformably on the Devonian Limestone. They are from 100 to 180 ft. in thickness, and are highly bituminous. The detrital material is almost pure silica sand. A well drilled near McMurray showed no evidence of oil in the Devonian, and Hume suggests that the oil has not come from the underlying Palæozoic rocks. In his opinion it probably originated in the McMurray beds, or their marine equivalents to the west of the outcrop, and was flushed into its present position by waters entering the outcrop farther west and driving the oil up dip.[30, pp. 96, 98] Presumably the time of these events was after the Laramide Revolution.

A well drilled for salt at McMurray revealed Upper Devonian fossils, but none of Middle Devonian age.[47] At the bottom of the well rocks were penetrated showing affinities with Silurian beds of the Great Slave Lake area.[9, p. 16b] There is reason to believe that in the salt-well Middle Devonian rocks (which are bituminous on Great Slave Lake) are missing, as they are at several other points in this region.[9, p. 12b] The hiatus is probably only local, and the McMurray sands are, in part at least, underlain by both Upper and Middle Devonian rocks. The latter may well be the source rock for the oil, for the records of many wells in this neighbourhood show that oil and gas are of frequent occurrence in the Palæozoic Limestone.[49, pp. 21-29]

Vegetable remains occur in the McMurray Tar sands, impregnated with bitumen and preserved with little alteration.[49, 50] For such preservation the bitumen must have arrived early on the scene, and the only reasonable source is in the underlying formations. The difficulty of flushing heavy oils from sandstone reservoirs with fresh waters is well known, and Nutting has discussed this problem from the physico-chemical aspect.[51, 52]

Evidence of Devonian oil has been obtained from wells in the Peace River Territory [63, p. 38] and also from Lesser Slave Lake.

In the Viking, Wainwright, Ribstone area heavy gravity oil and some gas occur in the Lower Cretaceous just above the Palæozoic contact, and two wells found traces of oil in the Palæozoics. The dry gas from Viking is from the Lower Cretaceous, but one well found some gas in the Palæozoic Limestone.

Small quantities of oil and gas were also found in the Fuego well, and 50 miles south-west of this in the Ontario Alberta well, both in the Palæozoic Limestone (see Plate No. 1).

Although the Medicine Hat dry gas (methane) comes from a sandy horizon in the Benton formation, the Roth well found a little heavy oil in the Palæozoics, and a similar " show " occurred in the Drazan well just east of Medicine Hat.

Other wells in the Plains area which had " shows " of oil in the Mississippian Limestone are: Warner No. 1, Commonwealth and Capitol wells, Milk River, the Eyremore and Keho wells, also the Parco Twin River and the Texas-Imperial Lethbridge. The Keho well also found some oil

in the Benton formation. The Devenish No. 3 well produced heavy oil from just above the Palæozoic Limestone for a short time.

At Spring Coulee the top beds of the Mississippian Limestone show oil saturation, and in the Red Coulee Field on the International Boundary oil occurs at the base of the Blairmore.

In the oil-fields of Montana, Wyoming, and Colorado published opinion in most cases favours source rocks of Upper Cretaceous and Jurassic age.[21, pp. 557-666] In the Grass Creek Field and elsewhere oil occurs in the Pennsylvanian, and on the eastern side of the Bighorn Basin oil is reported to be seeping from joints in the Madison (Mississippian) Limestone.[21, p. 629] The possibilities of a Palæozoic source for the Kevin-Sunburst oil in Montana has been discussed favourably by Perry and others.[53]

The oil and gas which is found issuing from the Pre-Cambrian rocks of the Lewis Thrust Sheet is generally believed to originate in younger rocks beneath the thrust fault.

Mackay [17] states that in the Crowsnest region bituminous matter is found associated with phosphatic material in Jurassic (Fernie) beds, and this is the only promising source rock that could be found, but Daly reports an outlier of Palæozoic Limestone on the International Boundary as far west as 114° 38′ W. in which "the larger calcite crystals are blackened by films of bituminous matter," and another outlier still farther west is "fetid or bituminous on the fresh fracture." [79, p. 111]

In Turner Valley oil and gas are present in all Mesozoic formations penetrated by the drill before reaching the naphtha-bearing Palæozoic Limestone, but there is no oil or gas in the Mesozoic rocks beneath the main fault. R. M. S. Owen, in a personal communication, has called attention to the association of the "Top-Shows" of the northern part of the Field with the area lying above the line of back-folding or under-thrusting in the Palæozoic Limestone. Mesozoic rocks also produce oil from some wells in the southern part of the Field, where strong subsidiary faults in the Limestone are also believed to be present, but cannot be defined with the same certainty as in the northern part.

The "gas" usually occurs in the top few hundred feet of the Limestone beneath a barren silicified cap, which varies in thickness in different wells. As stated previously, the porous zones are probably lenticular, and free communication is much restricted. Conditions in the Kevin-Sunburst Field are very similar, but in this case it is mainly oil which is present.

In the Moose Mountain well a naphtha-laden gas similar to that in Turner Valley occurs deep in the Devonian. There is not sufficient for commercial production, but the occurrence is interesting in view of the occurrence of light oil in the Devonian at Kevin-Sunburst.

(b) *Hypotheses Concerning Oil and Gas Accumulation.*

Hume, whilst admitting the evidence of petroliferous conditions in exposures of the Palæozoic Limestone, regards the oil and gas as having originated in the Jurassic. In the Plains area, except for the bituminous shale which occurs at the top of the Devonian, he states that no part of the Mississippian or Devonian appear bituminous. More to the north he regards the Lower Cretaceous as being the source of the oil and gas.[60]

In the writer's opinion it is improbable that the lighter petroleum constituents could migrate downwards and pass through a band of impervious limestone, which the evidence clearly indicates was silicified before the Jurassic beds were deposited, and become sealed within the porous reservoir under conditions of high pressure in which it now occurs. Moreover, the occurrence of lighter petroleum constituents in the Devonian in Moose Mountain and Montana, where possibilities of a Mesozoic source are improbable, if not impossible, should also be given due weight as circumstantial evidence.

Except in the case of the Spring Coulee well, there is a marked absence of bituminous matter in the Palæozoic Limestone sections from wells in the Plains area, but, in view of the many oil shows in these rocks, it appears unjustifiable to rule them out as source rocks on arbitrary grounds.

Suggestions have also been made that the oils associated with Palæozoic rocks in this petroliferous province are heavy and asphaltic, whilst Mesozoic oils are light and medium grade and of paraffin base.[60, disc.] Careful comparisons of available records show that no such division is possible. The various types of oil occur in the Palæozoic and Mesozoic rocks indiscriminately.[10, 53, 91]

Statements have also been made that the oil occurrences in the Turner Valley Mesozoics become progressively lighter with depth, but a careful comparison of the whole of the evidence provides no support for these statements.

It has been suggested that the gas in the Turner Valley Limestone has reached its present position by migrating upwards from a Mesozoic source beneath the main over-thrust fault.[60, disc.]

First, it should be remembered that no oil and gas have been found in the underlying Mesozoics in the McLeod No. 4 well. The channels for the postulated migration would be either fractures, or the main thrust fault, since the Limestone is for the most part impervious. Such channels would not stop short at the porous horizon, but would continue some distance into the overlying Mesozoics, and in this case the oil and gas would find their way into the sandstone reservoirs above the Limestone. Before this hypothesis finds acceptance some explanation must be offered of the way in which the "gas" could be sealed within the porous reservoir beneath a silicified Limestone cap. Also this problem cannot be dissociated from the Devonian oil and gas occurrences already mentioned. The evidence is to a large extent inter-dependent, and cannot be interpreted piecemeal.

The solid bitumen and the light petroleum constituents in Turner Valley have led to the seeking of an explanation for these peculiarities by the application of White's Carbon Ratio Hypothesis.[56] At least two supporters of this view have published their opinions.[10, p. 14; 57, pp. 53–56]

I. W. Jones [58] has reviewed the evidence in considerable detail, and shows conclusively that there is no apparent relationship between the Carbon-ratios of the coals and the grade of the associated petroleum products in Western Canada. In this connection it is of interest to refer to MacKenzie Taylor's conclusions,[65] and also to those of Strahan and Pollard concerning anthracites in the South Wales coalfield.[59] They show that the source material and the conditions in the early stages of coal formation play a large part in the type of coal which ultimately results.

Seyer has stated that petroleum of ancient origin, which has been subjected to a temperature of more than 200° C., would ultimately be transformed into gas and solid bitumen of high carbon content.[94]

In the outer Rocky Mountain Foothills the Mesozoic cover was probably less than 15,000 ft., and the corresponding temperature not more than 100° C. In the case of the bitumen illustrated in Photograph No. 5, it is apparent that it was already sufficiently solid to take the shape of the calcite rhombs before silicification took place; that is, before the Mesozoic cover was deposited. Moreover, similar bitumen is found in rocks as young as the Miocene and late Cretaceous Limestones of Iraq, and also in parts of the English Carboniferous Limestone where great thicknesses of cover have never been deposited; nor is there evidence of temperature elevation. In the many sections of the Turner Valley Limestone examined, no trace of metamorphic minerals has been observed. In the neighbouring structures to Turner Valley the Palæozoic Limestone contains small quantities of liquid petroleum of the normal crude type, and this, together with the other reasons given, prevents the acceptance of Seyer's hypothesis as an explanation in this case.

In the Laramide Revolution it is impossible to estimate the temperature rise which may have taken place. Harker [93] quotes evidence to show that in general over-thrust movements are so slow that any heat generated is dissipated before an appreciable temperature rise can take place.[93, pp. 331, 338]

In Turner Valley the only evidence of shearing stress comprises cracked quartz, undulose extinction, and twinned calcite, and according to Harker shear stress is not strongly developed in Limestones, owing to the yielding nature of the rock.[93, pp. 187, 254] Experiments to determine the effects of shear stress on petroleum products have so far failed to produce results from which general conclusions can be drawn,[96, 97] and in consequence conjecture as to the possible processes involved is unlikely to be profitable. It is better to rely upon the available evidence.

As already stated oils of various grades occur in the Turner Valley Mesozoic rocks, and also in the Palæozoic Limestone in nearby wells. All these rocks have suffered similar tectonic disturbance, and it is therefore difficult to understand why, if the Turner Valley "gas" results from these conditions, different results are produced elsewhere. To postulate special conditions for Turner Valley, without defining them clearly, is to beg the question.

(c) *Conclusions (Oil and Gas).*

The writer's conclusion that much of the oil and gas was formed in Palæozoic times has been reached without prejudice to any conception of the oil- and gas-forming possibilities of some Mesozoic rocks. Proof that this Palæozoic oil could survive the exposure and denudation of the reservoir rocks exists at Fort Norman, at Great Slave Lake, and in other areas.

In the metasomatic replacement of the Palæozoic Limestone by silica under the influence of meteoric waters in late Palæozoic times possibilities existed for oil and gas, migrating slowly upwards, to be separated and preserved, especially if gentle flexuring was present in the Limestone. Adsorption by silica and silicates as suggested by Nutting [51, 52] and Brooks [61] may have played some part in this process, and a separation

of the more mobile and lighter constituents into the smaller pores may have taken place by virtue of their low viscosity.

In the compression beneath the heavy over-burden of Mesozoic rocks the larger cavities in the Limestone probably collapsed, as Perry suggests in explanation of certain faulting in the Kevin-Sunburst Field,[53, pp. 11, 12] and this would also explain the brecciation of some horizons near the top of the Limestone in Canyon Creek. This collapse of the porous horizons would result in the expulsion of oil and gas into the overlying Mesozoics. In the further compression of Laramie times only the porous horizons with the very finest pores would escape collapse, and these contained the lightest constituents.

Owen's suggestion, that the "top-shows" in the northern part of Turner Valley are related to the "back-folding" in the Limestone, is an additional reason for believing that the Mesozoic oil and gas came from below as a result of fracturing in the Limestone.

The condition of the Limestone in the structural units to the west of Turner Valley indicates that fracturing has been so severe that nearly all the oil and gas have been dissipated and water channels have been opened up. In the case of Turner Valley the absence of water in the Limestone is probably due to the comparatively unbroken condition of the Limestone immediately to the west of this structural unit.

In the Plains areas it is not permissible to rule out the Palæozoics as source rocks, on account of the comparative absence of argillaceous strata. Limestones are eligible as source rocks, as Trask [98] and others have shown. The absence of oil and gas in commercial quantities in the Plains areas is, in the Author's opinion, a question of structural conditions, and probably the imperfection of the seal in many places. It is considered that from Montana to McMurray there is every reason to believe that the oil and gas occurring in the older Mesozoics, whether Jurassic of marine origin or Lower Cretaceous of non-marine origin, came originally from the underlying Palæozoics.

With regard to the oil and gas of the Upper Cretaceous, this may or may not have originated in the Palæozoics. Methane can be formed from a wider variety of material than petroleum, but its great mobility could account for its wide separation from a parent oil body. There is certainly no justification for connecting this gas with metamorphism in an attempt to force the application of the Carbon Ratio Hypothesis. The evidence precludes the possibility of very great thicknesses of cover rocks or of tectonic disturbance, even if their significance in this respect could be admitted.

4. Summary of General Conclusions.

1. The southern part of the Canadian Rocky Mountains was formed by the squeezing of a thick mass of geosynclinal strata between the Canadian Shield and a semi-rigid mass, the "congealed" stumps of the Jurasside mountains, on the west. It is probable, as Argand suggests,[24] that the Pre-Cambrian basement rocks of the Shield have also yielded to the compressive forces, for this was part of the much larger Cordilleran disturbance of Laramie times, and according to Kober [25] the westerly equivalent of the Canadian Shield foreland was the bed of the Pacific.

2. The result of this compression on the Rockies was to form a wedge-shaped orogeny with flat over-thrusts on the borders, and steeper thrust faults, the deeper parts of former flat over-thrusts revealed by elevation and erosion, in the interior of the range.

3. The eastern Foothills surface structures are mainly imbrications in incompetent Mesozoic rocks, produced by the shortening of the underlying competent Palæozoic Limestones by a few over-thrusts of moderate displacement. Turner Valley lies on the eastern edge of the Foothills above one such Limestone thrust sheet, which had not emerged at surface when the mountain building forces had found relief.

4. The profiles of the thrust faults in both the Mesozoic rocks and in the Palæozoic Limestone, in general dip steeply at outcrop, flatten at depth, and appear to pass downwards into folding at a steeper angle. The small thrust faults in the Mesozoics are for the most part not continued downwards to the Palæozoic Limestone.

5. The greater part of the oil and gas probably originated in the Palæozoics, although some source rocks may occur in the Mesozoics.

6. The naphtha-bearing gas in Turner Valley is preserved in a number of lenticular porous horizons near the top of the Palæozoic Limestone. The porosity has been formed by penecontemporaneous dolomitisation, followed by the leaching of calcium carbonate and sealing by deposition of silica by meteoric waters during the long period of exposure previous to subsidence, and the deposition of a thick Mesozoic cover.

7. The oil and gas probably migrated slowly into pre-Mesozoic flexures, and some of it was preserved in the pores and cavities as they were formed by solution, and sealed by secondary calcite and silica.

8. The collapse of the more cavernous zones in the Palæozoic Limestone took place as the result of compression under the Mesozoic load, and later owing to tectonic compression in Laramie times. Oil and gas were in consequence expelled into the overlying Mesozoic rocks, but large amounts of the lighter constituents were retained in the smaller voids in the reservoir rock, into which their low viscosity permitted migration.

9. Secondary silica and silicates may have played some part in the separation of the lighter constituents by selective adsorption, and the solid bitumen may have been formed by the polymerisation of unstable hydrocarbons whilst adsorbed by silica and silicates, the action being assisted by the heavy pressures of the Mesozoic overburden.

10. The following minor conclusions have been reached :—

(*a*) The Grit index horizon is a normal felspathic grit and, contrary to previously expressed opinion, has no apparent connection with the Crowsnest Volcanics to the south.

(*b*) The " Oolites " index horizon is formed of sphærosiderite concretions in a colloidal clay matrix.

(*c*) The bitumen in the McMurray " Tar " sands originated in Palæozoic Rocks.

Acknowledgments.

In conclusion, the Author feels that this paper merely touches the fringe of possibilities for detailed investigation of the large amount of material

which has been collected from wells in Western Canada. The results appear small for the time and effort expended, but this is to be expected, as only a small part of the material examined yields useful information. Every effort has been made to base hypothesis on a foundation of fact, but the structural interpretations have been generalised, as any cut-and-dried scheme of sections and contours, whilst purporting to represent actuality, with the evidence available, would of necessity be largely conjectural. Further detailed examination of the available well samples, especially of the Palæozoic Limestone, is a method of attack which offers good prospects for the collection of further evidence, without which no hypothesis, however ingenious, can hope to carry conviction.

The necessity for keeping the length of this paper within prescribed limits prevents the discussion of many points as fully as could be wished, and only a very few of the many photomicrographs have been reproduced, but it is hoped that the references given will in part compensate for these defects.

Former criticism has been of considerable assistance,[34, disc.] and for this and a large body of facts and opinions, drawn freely from many sources, the Author is grateful to persons too numerous to mention individually. A special debt is due to former colleagues of the Supervisory Mining Engineer's department in Calgary, whose assistance is gratefully acknowledged.

Some of the diagrams are based upon information published by the Canadian Geological Survey, supplemented in some cases by data from other sources. The Author wishes to acknowledge this but accepts responsibility for the present form and implication of these illustrations.

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LIST OF WELLS IN TURNER VALLEY.

Showing Index Numbers used on Plate No. 7.

1A. Invaders.
2A. Freehold No. 1.
2B. Dalfin.
2C. Vanalta.
3A. Calmont No. 5.
3B. Seneca.
3C. Stockmen No. 2.
3D. Turner Basin.
3E. Stockmen No. 1.
3F. Anaconda.
4A. Foothills No. 1.
4B. Model.
4C. Foothills No. 4.
4D. Vimy.
4E. Spooner No. 3.
4F. Dome.
4G. Midwest.
4H. United No. 5.
4J. ,, No. 4.
5A. Spooner No. 2.
5B. ,, No. 1.
5C. Vulcan No. 1.
5D. ,, No. 2.
5E. ,, No. 3.
6A. Dalhousie No. 6.
6B. Royalite No. 9.
6C. Dalhousie No. 3.
6D. Royalite No. 13.
6E. Dalhousie No. 2.
6F. Royalite No. 7.
6G. ,, No. 12.
7A. ,, No. 21.
7B. Illinois Alberta No. 1.
7C. Dalhousie No. 1.
7D. Royalite No. 18.
7E. Illinois Alberta No. 2.
7F. New McDougall Segur No. 3.
7G. ,, ,, No. 4.
7H. ,, ,, No. 2.
7J. Widney.
7K. Royalite No. 8.
7L. ,, No. 10.
7M. ,, No. 11.
8A. ,, No. 4.
8B. British Dominion No. 2.
8C. Royalite No. 20.
8D. British Dominion No. 3.
8E. Royalite No. 22.
8F. ,, No. 14.
8G. ,, No. 15.
8H. ,, No. 16.
8J. McLeod No. 2.
8K. ,, No. 1.
8L. ,, No. 3.
8M. ,, No. 4.
8N. ,, No. 5.
8P. Sentinel.
9A. Cooper Nanton.
9B. Royalite No. 17.
9C. Sioux City.
9D. Great West No. 2.
9E. ,, ,, No. 1.
9F. Royalite No. 3.
9G. Regent No. 1.
9H. ,, No. 2.
9J. ,, No. 3.
9K. Canada Southern.
9L. Midfield.
9M. Freeman Lundy.
10A. Royalite No. 1.
10B. ,, No. 2.
10C. Okalta No. 3.
10D. ,, No. 5.
10E. Foothills No. 2.
10F. Ranger.
10G. Okalta No. 4.
10H. Royalite No. 19.
10J. Okalta No. 2.
10K. Okalta No. 1.
10L. Calmont No. 1.
10M. Highland.
10N. Big Chief.
11A. British Dominions No. 1.
11B. Royalite No. 23.
11C. ,, No. 25.
11D. Structure.
11E. Midwest No. 1.
11F. Midroyal.
11G. Dalhousie No. 5.
11H. ,, No. 7.
11J. Royalite No. 24.
11K. ,, No. 6.
11L. Dome No. 2.
12A. Home No. 4.
12B. Advance 5A.
13A. Home No. 2.
13B. Baltac.
13C. Home No. 1.
13D. Calmont No. 2.
13E. Home No. 1A.
13F. Calmont No. 8.
13G. ,, No. 10.
13H. ,, No. 11.
13J. ,, No. 12.
14A. Hargal No. 1.
14B. Calmont No. 7.
14C. A.P. Con. No. 1.
14D. Calmont No. 6.
15A. Home No. 3
15B. N.W. Associated No. 1.
15C. ,, No. 2.
16A. Freehold No. 2.
16B. A.P. Con. No. 2.
16C. Home No. 5.
16D. ,, No. 6.
17A. Wellington No. 1.
17B. Lowery No. 1.
17C. Mayland No. 4.
17D. ,, No. 1.
17E. Lowery No. 2.
17F. Homestead No. 1.
17G. Mayland No. 2.
18A. East Crest No. 1.
18B. Mayland No. 3.
18C. East Crest No. 2, & 2 A.
18D. Mayland No. 6.

19A. East Crest No. 3.
19B. S.W. Petroleums No. 2.
19C. Southern Lowery No. 2.
19D. Foothills No. 3.
19E. Miracle No. 2.
20A. Commonwealth.
20B. Mercury No. 1.
20C. Spray.
20D. Hylo.
20E. Southern Lowery No. 1.
20F. Miracle.
20G. Mercury No. 2.
21A. Mill City.
21B. Mercury No. 5.
21C. ,, No. 3.
21D. Sterling Pacific No. 1.
21E. ,, ,, No. 2.
21F. Livingstone.
21G. Sterling-Royalite.
21H. Anaconda No. 2.
21J. Sunburst Midroyal.
21K. Marjon No. 2.
21L. Merland.
21M. Freehold No. 4.
21N. Publix.
21P. Pacalta.
21Q. Spooner Anaconda No. 1.
21R. C. & E. Longview.
21S. Hoffar Lundy.
21T. Union.

CHEMICAL ANALYSIS OF THE PALÆOZOIC LIMESTONE.

Siouz City Well. Amounts by weight in 100 gms.

Depth.	Calcium.	Magnesium.	Silica.	Depth.	Calcium.	Magnesium.	Silica.
4390	11·3	2·7	25·8	4730	13·4	9·4	12·5
4400	15·2	5·6	22·6	4740	13·27	4·0	50·5
4410	20·1	11·6	5·1	4750	24·4	8·4	7·8
4420	21·7	11·2	3·9	4760	23·8	10·22	2·8
4430	29·5	4·2	3·4	4770	23·8	9·0	3·3
4440	36·4	2·1	1·2	4780	15·6	5·0	40·86
4450	22·8	12·3	0·2	4790	26·6	4·0	16·8
4460	21·1	10·8	5·8	4800	21·7	2·7	16·7
4470	19·5	9·3	10·9	4810	21·1	9·7	12·3
4480	19·1	8·2	13·7	4820	22·9	9·2	9·5
4490	20·1	6·5	11·5	4830	35·9	1·3	5·3
4500	18·3	9·2	18·4	4840	32·2	3·5	6·9
4510	15·6	7·8	29·4	4850	38·21	0·9	1·4
4520	14·9	7·5	32·4	4860	29·3	6·5	3·6
4530	16·2	8·4	26·0	4870	35·3	2·3	2·2
4540	14·5	7·1	30·6	4880	36·6	1·9	1·8
4550	16·4	7·9	23·5	4890	35·3	2·8	2·2
4560	20·4	10·7	5·4	4900	37·2	1·9	0·5
4570	21·5	12·6	0·6	4910	38·2	0·4	0·7
4580	21·7	12·6	0·2	4980	38·2	0·5	0·8
4590	21·7	12·3	0·1	5050	39·0	0·3	0·5
4600	21·5	12·7	0·1	5110	38·4	0·1	1·8
4610	20·8	11·9	3·8	5200	35·2	1·0	5·0
4620	20·8	11·9	5·7	5260	37·3	1·1	2·6
4630	20·3	11·3	3·4	5300	37·0	1·1	2·2
4640	21·3	12·2	1·5	5400	33·2	0·3	5·2
4650	21·6	12·75	0·6	5510	36·0	2·0	3·0
4660	21·8	13·0	0·6	5610	26·2	6·0	13·0
4670	21·7	12·6	0·7	5710	36·04	2·0	5·0
4680		missing		5810	29·0	2·5	17·6
4690	21·8	12·5	0·6	5910	36·0	1·5	10·0
4700	21·7	11·4	7·1	6020	23·3	2·7	30·1
4710	19·6	9·4	12·5	6110	26·2	2·0	26·0
4720	18·5	7·6	16·0	6170	30·2	trace	24·3

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NOTE ON ADDITIONAL LITERATURE. The 1933 Edition of Dr. G. S. Hume's "Oil and Gas in Western Canada" was not available until this paper was complete, and apologies are offered for any comments which may be rendered unnecessary by Dr. Hume's modifications of his previously expressed opinions. Also only recently has it been possible to obtain a copy of the report by Dr. C. S. Evans on the Brisco–Dogtooth Map Area, B.C. (G.S.C. Summary Report 1932, Part A.2), in which an interpretation of the general structure of the Rocky Mountains is given.

Recently Dr. T. A. Link has been good enough to forward a pre-print of part of his paper on Turner Valley, which will probably be published in the January 1935 number of the *A.A.P.G. Bulletin*. His opinions differ from the Author's on many points, and readers should refer to this and a joint paper by Mr. P. D. Moore for the other point of view.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE One Hundred and Sixty-Third General Meeting of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, February 12th, 1935, **Mr. T. Dewhurst,** President, in the Chair.

The President said he had very much pleasure in announcing that since the last meeting a Burma Branch of the Institution had been formed and was now in being. (Applause.)

The following paper was presented :—

NOTES ON THE PETROLEUM GEOLOGY OF WESTERN CANADA.*

By A. J. GOODMAN, B.Sc., Ph.D. (Associate Member).

DISCUSSION.

The President said that the subject of the paper was one of great interest to petroleum geologists. It was also very important to Canada, and therefore to the Empire, and in this connection it was noteworthy that Dr. Goodman had been almost silent on the very important subject of the prospects of the discovery of other valuable oil-fields in the region. He was sure that members would be grateful if Dr. Goodman could see his way to express, even in general terms, any views he held on this most important subject.

There were many interesting problems connected with the geology of Western Canada, but to petroleum geologists the most interesting, and also the most intriguing, was that of the geological age of the source-beds of the oil. This was a difficult problem in regard to most oil regions, and was particularly so in the region under discussion, as migration of oil from one formation to another had been rendered possible, or facilitated, by the extensive thrusting that had occurred, and by the presence of a very important erosional unconformability. As in other regions, it seemed probable that conditions suitable for the formation of oil had occurred at several stages during the in-filling of the geosyncline. There seemed to be no sound reason why suitable oil-forming conditions should not have existed during certain epochs of the Palæozoic and Mesozoic eras. However, he personally would be inclined to suspect that particularly favourable conditions for the formation of petroleum might have existed during the deposition of those beds which were situated near to and above the Palæozoic/Jurassic unconformability.

It was reasonable to hope for, and even to expect, an interesting and illuminating discussion on the subject. Indeed, the Author's definite,

* See pp. 221–258.

uncompromising, and, one suspected, somewhat unpopular attitude on the subject of the source of the oil was bound to provoke discussion. It was therefore fortunate that several technologists present were familiar with the region in question and were capable of expressing clear and definite opinions which might not be in accord with those set out in the paper.

Mr. E. H. Cunningham Craig said that there had been many misunderstandings with regard to the geology of Alberta, and even now, as Dr. Goodman had shown, there were many points still to be cleared up.

The petrological work that Mr. Goodman had done was of great importance. Not every geologist visiting Alberta had either the time or the facilities to undertake indoor petrographical work, so the results that Mr. Goodman gave in this paper would be of great value in enabling field geologists to identify stratigraphical horizons.

It was almost exactly twenty-three years since he first began field work in the foothills, and he had continued it at intervals ever since, always learning a little more. He confessed that he was still learning, but from work in the field, mapping on the six-inch scale, rather than from indoor work or the study of publications.

In the history of geological work in Alberta, there had been many mistakes made both in stratigraphy and structure, and many published maps had had to be corrected, re-issued and corrected again, before the present position had been attained. This applied also to published cross-sections, which of course were more in the nature of opinions than statements of fact. Physical impossibilities had appeared more than once both in maps and sections. Now the main points are fairly well agreed upon, though theoretical matters in some cases are still subjects of controversy.

He was glad to note that Dr. Goodman had referred to the experiments of Mr. H. M. Cadell. These were made while H.M. Geological Survey of Scotland were unravelling the problems of the North-Western Highlands during the classical research that resulted in giving to the world the first account of thrust-planes. Though it was found impossible to reproduce the same conditions artificially, Cadell's practical demonstrations were of considerable value, especially in calling attention to the dynamics of earth movement. Thrust-planes took the geological world completely by surprise, and geologists from every country came to study them in N.W. Scotland : they arrived sceptical, but left fully convinced.

Nowadays everyone knew thrust-planes, and they were sometimes mapped rashly by young geologists where nothing of the kind occurred, and where they were not physically justified. H.M. Geological Survey made sure of at least two important points—namely, that in an area where intense folding and also thrusting were observed, the thrusts were the latest movements, though they might die out in folds at depth. They were the breaking waves in earth movement, occurring under less load than folds. The other point was that action cannot come from the unloaded side. This brought him to one criticism that he wished to make, though he was fairly sure that Dr. Goodman was not responsible for any error that had been made in this particular connection. He showed, as had other geologists in Alberta, thrust-planes beginning at a steep angle and

flattening out. The physical possibility of such a structure had never been justified; it was an action from the unloaded side.

What really occurred was that steep faults, always somewhat reversed, rode on the thrusts, and these dislocations had been confused with the thrusts. The outcrops of the thrusts were seldom observed, whereas the rider faults were frequently seen. They were minor structures, though often with considerable throws, and were almost invariably found accompanying thrust-planes.

The exaggerated thickness of the Alberta Shales often shown was usually due to rider faults which had not been detected.

He could confirm Dr. Goodman's account of the general geological structure and the manner in which the foothills country was built up by a series of thrust-planes in echelon. Though these dislocations overlap, one decreased in throw as another increased, and the dying out of a thrust as it passed into a sharp fold could actually be seen.

"Protected" areas between thrust-planes did exist, as Dr. Goodman had suggested, and occasionally they afforded favourable structures for the accumulation and preservation of petroleum, but such localities were rare, and none had yet been tested thoroughly by the drill.

It was the "rider" or imbrication faults that called attention to the presence of thrust-planes beneath: they all threw in the same direction. Strike faults which threw in the opposite direction only occurred on the flank of sharp anticlines that had occasionally been formed in more or less protected areas; they were merely adjustment dislocations of little importance.

The question of the original source of the oil and gas in Alberta had for many years been a subject of discussion, but he had believed that the Palæozoic origin hypothesis had been abandoned. It was necessary to take a broad view of the subject, and to compare Alberta with other countries where similar and almost identical conditions had been studied.

Dr. Goodman's view was based on at least one assumption, viz. that the dolomitisation of the limestone had taken place shortly after its deposition.

It seemed more probable that this dolomitisation was of post-Triassic age. The traces of hard insoluble bitumen in the limestone might, from Dr. Goodman's account, have no connection with the oil and wet gas, though certain oil-stainings he (Mr. Craig) had observed in porous bands of the limestone were doubtless due to a later impregnation. Had the dolomitisation been early, and the oil of Palæozoic age, the porous bands would be choked with ozokerite, not filtered oil and wet gas. The filtration evidence was quite clear if studied on a large scale. There had been migrations across rider faults from lower to upper horizons, accompanied by marked filtration, while the filtration downwards from a highly fluorescent and fairly heavy oil through red-brown oil with little fluorescence to straw-coloured and water-white oils to wet gas, and finally to almost dry and sulphurous gas, was a fact that cannot be ignored.

A study of the Kootenay Beds in their two phases, carbonaceous and petroliferous, yielded data the meaning of which was quite obvious.

The idea that the tar-sands of the Athabasca, extending over 10,000 square miles, could have been impregnated with a heavy asphaltic but

still gassy oil from slightly porous Palæozoic beds, in which only traces of filtered residues were found, was inconceivable.

The Fort Norman oil was filtered, and was not associated structurally with the Devonian limestone, and the only localities where heavy oil was observed in joints in that limestone were where the tar-sands had been recently removed by denudation.

Taking all the evidence into consideration, and judging from analogies with other countries, the conclusion seemed inevitable that the basal Cretaceous strata were the original source of the oil.

Except on this question of origin, he was in general agreement with practically everything Dr. Goodman had said.

Mr. Campbell M. Hunter said that in the course of his frequent visits to Western Canada during the past few years he had come in contact with so many different expressions of opinion that it was refreshing to find an authority like Dr. Goodman coming out into the open and giving such an admirably documented paper supported by such a wealth of detail (Dr. Goodman having made about a thousand slides before selecting the few he had shown that evening). Such a paper therefore could not fail to have a very great bearing on the better understanding of this very complicated foothill zone.

Dr. Goodman's views had not been fully accepted in the past in Canada; in fact, his original paper had been subjected to much good-humoured criticism. But the present paper struck a new note, since it approached the problem from the scientific rather than from the practical point of view. He did not wish to under-estimate the practical aspect, but it was refreshing to come across a problem tackled essentially from the scientific aspect.

There were points in which Dr. Goodman was at variance with other accepted authorities in Canada. Those members who had studied the matter were familiar with Dr. Link's, Dr. Hume's, and Mr. P. D. Moore's writings on the subject. These were all men to whom one must pay attention because they had devoted many years of their lives to the study of these problems, and he was looking forward to reading in due course their criticisms of the present paper.

There were certain conclusions arrived at by Dr. Goodman which, he thought, would be accepted as opening a new chapter in the understanding of this particular zone. In particular he referred to Dr. Goodman attributing such a large part to the Palæozoics in the origin of oil—and establishing that oil was present and indigenous in the Palæozoics. Dr. Goodman's arguments were extremely interesting and, in his opinion, water-tight. At first sight one might imagine that when that enormous Palæozoic mass had been uplifted, there would have been much sweating and escape of oil during the vast period of time during which it had been exposed to the elements. On the other hand, the fact remained that at the Great Slave Lake these same Palæozoics were still sweating oil. Another interesting feature was that in the wells in the Kevin–Sunburst field the accepted practice now was what they called "acidosing" wells. Thus wells often came in yielding several hundred barrels of oil per day, but after a short while their yield would fall off, and ultimately cease. By treatment with hydrochloric acid, wells can very frequently be brought back into increased

production, thus proving that there was a definite limit to the amount of oil that can flow into the well, which limit can be greatly extended by reducing or dissolving the lime. This interesting phenomenon confirmed Dr. Goodman's contention that because a limestone mass had been exposed during long geological periods it had not necessarily bled itself dry. A further sidelight on this question is thrown by the varying depths in the lime at which commercial production is obtained in recent wells drilled in the south end of Turner Valley. These depths range from 101 feet in the lime in the case of Mercury No. 1 well, to 1083 feet in the C. & E. Longview well, whilst the most prolific well—namely, that of the Highwood-Sarcee Company—was completed at 412 feet in the lime.

It was unfortunate Mr. Cunningham Craig had left the meeting, since he held definite views as to the origin of oil with which others were perhaps not in agreement. Mr. Craig may have had occasion to change his views, but he knew that some little time ago Mr. Craig considered the coal-bearing Kootenay Formation as being the most probable source rock. On the other hand, Dr. Hume had submitted a paper to the International Congress in which he had stressed the fact that the Jurassic, *i.e.* the Fernie shales, were the mother rock. That was accepted by Link and Moore—both being accepted authorities in Canada. Personally, he could see a certain amount of justification for both points of view, and he saw no reason why both should not be right. It was not a sign of weakness for one to stand with one's back to an open door, and that was what one wanted to do in a case of this sort. Indeed, it was what one would have to do until many more wells had been drilled in areas other than Turner Valley. At present the Turner Valley Field rather warped most people's point of view. Although 100 wells had been drilled in that Field, its area was comparatively limited; hence no complete solution of the problem could be deduced from the results obtained there. New structures, however, were being tested in the South, though whether they would prove oil-bearing remained to be established. One field was being tested to the North which, if successful, would throw valuable sidelight on this problem, and possibly help both Dr. Goodman and Dr. Link in joining their ideas and coming to a final decision, thus enabling the practical oil-field driller and operator to do what all concerned wanted to do—namely, open up new fields much less complex and less deep than the one at present in exploitation.

Dr. Goodman deserved great thanks for his contribution to this subject to which he had devoted many years of study, and it was not often that a paper was put forward with such documentation.

Dr. G. M. Lees remarked that he always found Alberta oil-field geology a stimulating subject for discussion. Dr. Goodman's paper had considerable value both on the factual and on the provocative side. He did not agree with Dr. Goodman's structural interpretation of Turner Valley, as he thought the thrust fault was more than a subsidiary feature on the flank of an overfold dying out with depth. Dr. Link had recently shown the fault as completely decapitating the limestone fold, and therefore being tectonically unrelated to it. He (Dr. Lees) thought the truth would probably lie between these two extremes.

The origin of the oil was another provocative issue on which he was not

in agreement with Dr. Goodman. In the discussion on Dr. Hume's paper at the World Petroleum Congress, he (Dr. Lees) had stated his opinion that the regional evidence was in favour of a Mesozoic oil which at Turner Valley had gained entry to the Palæozoic Limestone from under the thrust block. Dr. Goodman had rather categorically denied the validity of the regional argument, but in spite of this denial he still adhered to his point of view. Although several wells in Turner Valley had reached the thrust fault, only one had penetrated to any distance below it, and the results of this one well are a totally insufficient basis for a definite statement that there is no oil in the lower block of the fault system. The very nature of the Turner Valley oil suggested that it is not normal or *in situ*. Wet gas of this type is usually directly or indirectly associated with reservoirs of normal crude, *e.g.* Big Lake and Kettleman Hills, and he thought that the Palæozoic reservoir of Turner Valley must have been fed from a normal accumulation either vertically below or displaced some distance to the west.

Prof. V. C. Illing said that he had had some association with Dr. Goodman's work in the laboratory, and he could add his own meed of praise for the painstaking work which Dr. Goodman had done, and the enormous amount of section cutting and examination which he had carried out before he had reached his conclusions.

He desired to stress the point that the paper gave petrographic evidence in detail, which would assist one in getting to the bottom of the whole question of source rocks. He was glad to see that Dr. Goodman used due caution in that evidence, particularly with regard to the bitumen in the oolites and other sources. One knew from impregnations of other asphalt rocks how easy it was for bitumen to get through the constituent parts of grains and to select certain portions for its accumulation, without leaving any trace of its passage. He thought that Dr. Goodman had threaded his way through these difficulties with success and had reached conclusions which seemed to him to be well supported by the evidence which Dr. Goodman had put forward.

The question of source rocks was a difficult one, and Dr. Goodman had done those interested in the subject a service in stressing one point of view. Perhaps in doing so there was a danger that his views of a Palæozoic source rock were over-stressed, but at any rate it provoked discussion. The speaker felt that Dr. Goodman would agree that when one looked south to areas in Wyoming and Montana one must not close one's eyes to other possibilities. Dealing, as one was, with a geosyncline of deposition through long geological periods of time and with recurring similar environments, it seemed impossible to keep out of one's view the possibility of several source rocks. Personally, he felt it was not a weak standpoint to say that the truth would lie between the opposite points of view.

With regard to structural questions, so many points of importance and interest were raised in Dr. Goodman's paper that it was quite impossible to deal with them during the time at disposal. Personally he would like to range himself on Dr. Goodman's side on the question of structures in the Turner Valley. He thought that Dr. Goodman's interpretation was far more conservative, and fitted in more with the probabilities of the case than the idea of more extensive thrusting. He would like to ask Dr.

Goodman with regard to the structural complications, were not the conditions of lithology so different that a good deal of the differences in structure were the effects of beds of different competency reacting to the stress? It seemed to him, looking at one of the maps showing the outlines of the higher horizons and the substructure of the limestone, that the general relationship of the two suggested that there could not be extensive over-ride of a thrust type, but more of the reverse fault type of structure.

Mr. P. von Weymarn, in a written contribution, said that Dr. Goodman had very ably supported the view of the Palæozoic origin of hydrocarbons found in the Palæozoic limestones and had opposed the opinions favouring their Mesozoic source—whatever the way of migration—" without prejudice to any conception of the oil- and gas-forming possibilities of some Mesozoic rocks." Being of the same opinion, he wished to add some arguments which had not been mentioned by Dr. Goodman.

Hypothesis of the Mesozoic origin of the hydrocarbons found in the Palæozoic beds, obviously presumed either " downward migration " or structural conditions suitable for upward migration from younger rocks to the older ones.

It was well known that direct downward migration of liquid or gaseous hydrocarbons was a less common phenomenon than upward migration. It might occur only under special conditions of stress, porosity, etc. Absence of water in some cases, and presence of it in the others, might equally cause downward displacement, though physical laws governing it would be different. Therefore, when the assumption of downward migration was made, an adequate explanation as to the cause of it ought to be always given. A special difficulty was afforded by the case when a " downward squeeze " under the lateral stress was assumed. It must not be forgotten that the liquid was reacting hydrostatically—that is to say, transmitting the stress equally in all directions. Consequently, its displacement would be controlled by the directions of the least resistance, which were usually upward (relief of load by arching, exfoliation, tensional fractures, etc.). A downward squeeze seemed to be probable—mainly (if not only) *within the downthrow side of an over-thrust*, where the upward relief was made more difficult by the increase of over-burden, where the vertical component of the acting stress was pointing downward and where the fractures were compressional, viz. tending to close. He would return to this point later, when discussing Dr. T. Link's and Mr. P. D. Moore's hypothesis.

A case of interest in connection with the question of downward migration was the Athabasca Tar Sands region. Possibilities for either a gravitational seep, or an interchange of oil and water between Clearwater Shales and subjacent porous McMurray Sands (both L. Cretaceous), must not be entirely disregarded. It was difficult, on the other hand, to accept Dr. Hume's view that the source of bitumen here was (quoting from Dr. Goodman's paper) " the McMurray beds, or their marine equivalents to the west of the outcrops," and that the bitumen " was flushed into its present position by waters entering the outcrop farther west and driving the oil up dip." The objections were : the advanced oxidation of the bituminous matter in the sands—even in places which were now covered with heavy over-burden

—suggested that the sands had been flushed by oil very early in their history —when they were surface rocks with free access of air. (The well drilled at Pelican Rapids, very far from any outcrops of tar-sands, penetrated them at the depth of 750 feet. Thick tarry oil made impossible further drilling progress. The gas contained beside hydrocarbons—CO_2, 1 per cent.; free O_2, 2·9 per cent.; free N_2, 12·6 per cent.) Further (out of his own observations) in some places (along Clearwater River) the sands had no other cementation, but bitumen and the well-rounded and assorted quartz grains appeared to be of æolian deposits. This had the same significance as above. Both facts excluded contemporaneous origin of oil.

In addition to the facts mentioned by Dr. Goodman as pointing towards the possibility of a Devonian source of the bitumen, he mentioned that in his well on the banks of Clearwater River—about 35 miles east of Fort McMurray, he obtained a streak of bituminous limestone a few feet thick and some petroleum-smelling gas at the depth of 370 feet. The surface rock and the whole section of the well down to that depth was a hard compact limestone with no trace of bitumen. The tar-sands wedge out 10 to 15 miles east of Athabasca River, and the well had been located several miles east of their limits.

As to the application of the downward migration hypothesis to the area of the foothills, the main objection to it (beside those mentioned in Dr. Goodman's paper) was :

There were above the Madison Limestone many streaks of porous sandstones quite suitable as reservoir rocks. They should have been impregnated by hydrocarbons if the source rock were the superimposed Mesozoic shales and if the migration proceeded downward. But these sandstones were "dry," whereas closer to the Palæozoic beds and very near above the Jurassic marine shales (Fernie), there were a few oil- and gas-holding sands (to this series belong "Home" and "Dalhousie" producing sands). Their stratigraphic position, in connection with the above argument, suggested that their source rock was Fernie shales (or that they were secondarily impregnated from the limestone reservoir) rather than they had got their oil from the superimposed Cretaceous shales.

During the discussion which followed the reading of Dr. Goodman's paper it was mentioned that Dr. T. Link and Mr. P. D. Moore had developed a hypothesis, which, being of the "upward migration" kind, eliminated a great deal of objections to the Mesozoic origin of oil and gas in Turner Valley field. Their hypothesis, as far as it needed tectonic support, was based upon the logs of some wells (especially the very important McLeod No. 4), and, in general, it was in accordance with the present conception of Turner Valley structure. It was now understood that the crest of the folded Palæozoic beds had taken part in the thrust movement and had been dragged over the Mesozoic beds. The tentative section reproduced in Dr. Goodman's paper (Plate No. 4, fig. A) showed this feature. It represented a typical recumbent fold with the core of the Palæozoic limestone developed by the continual stress into an over-thrust—the "Main Thrust Fault" of Dr. Goodman. This (or similar) structure had suggested to Dr. T. Link and Mr. P. D. Moore the possibility of "upward migration" of hydrocarbons from the younger over-ridden Mesozoic rocks into the superimposed Palæozoic limestones.

The objections to this view were :—

Firstly, as the limestone core of the recumbent fold was reacting plastically, no tensional fractures could have been developed on its basal part. The only ones possible would be on its crest—opening upward and closing in the middle of the core—in the " neutral zone " where neither tension nor compression occurred.

Secondly, there was an opinion, well based on theory as well as on field observations, that thrust-planes in general were not means of escape of hydrocarbons, but that, on the contrary, they sealed the structure and prevented escape. The fractures were compressional, tending to close. The movements of the rock masses along the fractures were accompanied by powdering (milonitization) of the rocks and the thrust-planes were so tightly packed that they remained quite impermeable.

If the " Main Thrust Fault " had ever been a means of migration, there would remain no oil and gas in the Turner Valley structure. There were no seepages known along the thrust-plane, whereas along the crest, where tensional fractures were to be expected, seepages of gas were known.

As mentioned above, the structural conditions of Turner Valley field were such that a downward squeeze might be expected rather than an upward migration through the thrust-plane.

It remained to say a few words about the Turner Valley's " main puzzle " —occurrence of " wet gas "—which has been so differently interpreted by different geologists, and which gave rise to the well-known pessimistic outcry : " There is no oil in Alberta—only wet gas."

Using for interpretation of the field evidence the most common principles of petroleum geology, one might say at the present time (especially with the help of the section given in Dr. Goodman's paper) that there was no longer any puzzle in Turner Valley.

The following points were of importance :

Firstly (presuming that the Palæozoic rocks were the source of the hydrocarbons, and that for a certain period of time lateral migration could have proceeded unhindered by recrystallisation, viz. the rocks have had an even porosity, the bedding planes were not yet obliterated, etc.), the source rocks were covering such an immense area that the oil- and gas-traps (suitable structures) as large as they were, were not big enough to handle the enormous amounts of the percolating hydrocarbons. According to the law of specific gravity, the lighter hydrocarbons had been trapped first and had occupied very large parts of the structures, from the top down the flanks. The oil should be looked for on the flanks where they were technically reachable.

Secondly, the present Turner Valley field was the uppermost edge of a pseudo-monoclinal structure, rising far above the mother-fold from which it had been developed by dragging and overthrust. It was obvious that under the above-mentioned conditions of accumulation of hydrocarbons only the lightest ones might be expected to be found there. The structural conditions (overburden and dip) prevented any drilling on the western flank, where oil might be expected. Thus, for the time being, the Turner Valley field would remain a " freak of nature "—a " wet gas field." But there was no reason to ascribe these conditions to the whole petroliferous province. The positive result of the discovery of Turner Valley was the

evidence of great accumulations of hydrocarbons. The body of oil connected with such huge masses of gas must truly be a big one.

At the present time it was quite obvious that other structures remained to be drilled in search of oil—those the tectonic features of which indicated that the Palæozoic limestone did not take part in thrusts, but had been folded in anticlines and domes. Such structures undoubtedly existed, and he believed that at least two or three of them were already discovered, though not yet definitely tested by drilling.

Concerning Dr. Goodman's statement regarding " the marked absence of bituminous matter in the Palæozoic Limestone sections from wells in the Plains area," most certainly it was " unjustifiable to rule them (the Palæozoic limestones) out as source rock " on these grounds. One must, namely, expect that the " pay streak," that was to say—the upper part of the Madison Limestone was wedging out eastward and is eroded away northward and north-eastward during the pre-Jurassic erosional interval. The lower parts of it were " dry " also in the foothills. (Compare P. D. Moore's statement on bevelling of pre-Jurassic unconformity—" Palæozoic of Southern Plains of Alberta," *Bull. A.A.P.G.*, 1931, **15**, No. 10.).

Mr. R. M. S. Owen, in a written contribution, said that the title of the paper appeared to be too comprehensive for the subject matter actually discussed therein, which chiefly dealt with the structural geology of the Alberta foothills with special reference to Turner Valley. This restriction, coupled with the mere passing reference to other developed oil-fields and gas-fields in the plains of Alberta, would tend to leave the reader with the impression that major expectations of future petroleum production were to be hoped for only within the foothills area of Alberta; a supposition which the writer believed would eventually prove to be far from the truth.

While the Author had prepared a good case for the Palæozoic origin of at least part of the oil found in Turner Valley, it would appear to be distinctly dangerous to infer that the many occurrences of oil at different geological horizons throughout Alberta had had a similar origin.

It was stated as an argument against the possibility of migration of oil and gas from the underlying beds into the Turner Valley limestone that McLeod No. 4 had found no oil or gas in these underlying beds. While this was true to date, it should be mentioned that at present this well had penetrated only the upper half of the Benton formation below the sole fault, while the only porous horizons so far encountered in which oil or gas might have been expected had been the repetitions of the Cardium sandstone, a particular bed not known to be elsewhere petroliferous. Should this well ever reach the underlying Blairmore or older formations it might yet encounter petroliferous beds from which the limestone in Turner Valley might in large part have derived its present petroliferous content. In this connection the recent strike of wet gas close to the base of the Benton formation in the Ranchmen's No. 1 well located in l.s.d. 16, S. 13, T. 20, R. 29, W. 4th, in the plains area immediately to the east of Turner Valley, showed that the direct continuation of beds lying beneath the sole fault of Turner Valley, but not yet reached by any well in that area, were certainly petroliferous immediately to the east, and the same condition might be

found to exist directly beneath Turner Valley should the entire section of Mesozoic rocks beneath the sole fault ever be penetrated.

Mr. W. Calder, in a written contribution, said that the plains area of the Province of Alberta, although tested by wells at a few isolated points, remained a riddle to the geologist, and would continue as such owing to the glacial over-burden which precluded the locating of underground structures which must exist at depth. As regards the territory in the north extending to McMurray and some distance beyond Fort McKay, this was sparsely populated and, being mostly covered with muskeg, geological conditions were absolutely unknown except for the area where the tar-sand deposits occur, and therefore the author's conclusions on the latter appeared premature.

In view of the foregoing, a more appropriate title for the paper would have been "The Turner Valley Overthrust."

Aside from these considerations, the work must be classed as an outstanding contribution to oil-field structural geology, and the Author deserved full credit for this valuable piece of work.

As would be noted in the very complete bibliography attached to the paper, considerable study of the surface geology had been made in the Alberta foothills of the Rockies. In most cases these studies had covered considerable terrain and, although very informative, much more valuable information might now be available if the past work had been concentrated and more time spent in studying particular areas. As an example, the study of the areas to the west of Turner Valley, although informative, must be classed as sketchy as the time allotted for field work was in all cases limited, and did not permit of proper deductions regarding the underground structures. As regards the area to the east, this is quite unknown; therefore until underground conditions are clarified in both areas any conclusions in regard to the origin of the Turner Valley crude oils and naphtha were speculative.

Active gas seepages had been reported from many points along the full distance of the Alberta foothills, while natural gas could be obtained at comparatively shallow depths at most points in the plains; it was therefore permissible to presume that all these gas indications must be emanating from a vast common oil source possibly located at great depth.

Dr. A. J. Goodman, in reply, said that he had challenged published opinions with certain evidence, and expected that in turn his own views would be so challenged. Out of it he hoped there would come conclusions, at least on some points, which agreed with the whole of the facts as we knew them.

In replying to the President's inquiries regarding future oil-fields in this region, he wished to be cautious to avoid giving wrong impressions. The hypothesis which Stewart had put forward with regard to the structures lying to the east of the Lewis Thrust appealed to him in spite of the subsequent drilling results. Moose Mountain in some respects appeared to be a similar case, and he thought that there might be other examples of Palæozoic Limestone folds, arrested early in their development by the overriding of a higher thrust sheet. In localities where this thrust sheet had

been eroded and the underlying structures revealed, it might be possible to reach the Palæozoic Limestone with the drill. In cases where the thrust sheet was still intact, *e.g.* the Lewis block, it would be very difficult, if not impossible, to locate a well by any logical method. It seemed doubtful if geophysical methods would be able to help much either.

There may have been warping of the Palæozoic Limestones beneath the present Plains areas before the Mesozoics were laid down. If other conditions were favourable, concentration of oil may occur; if this was so, the location of such hidden structures would not be easy, and pre-Jurassic erosion was a factor which had to be borne in mind. Concerning oil and gas shows in the Mesozoics, suitable structural conditions at surface seemed so scarce that he found it difficult to be optimistic in spite of the very many indications of oil and gas which Plains wells had revealed. Others held quite different views, and he would be glad to hear on what grounds they held these views.

He was not sure that he fully understood Mr. Cunningham Craig's statement that "action cannot come from the unloaded side." Probably this was because their conceptions of the manner in which these structures were formed were quite different. Personally he favoured the "contractionist" view, and therefore direction of pressure and reaction, load and resistance all appeared to be relative. Pressure box experiments, diagrams and the like were only illustrations of certain aspects of the whole. In his opinion the profiles of the thrust faults which Mr. Cunningham Craig could not accept were amply justified by the evidence at surface, the evidence from wells, experiments by several geologists of repute, and an analysis of the mechanics of such structures. All these points were referred to in the text and in the references attached. He had already stated in the paper that he did not believe that the structural conditions of the North-west Highlands could be applied to areas where conditions, especially those of competence of the various rocks, were so markedly different.

He considered that the questions of dolomitisation, bitumen occurrence, and other points mentioned in the paper had been fully discussed there. Mr. Cunningham Craig had not attacked the arguments, but had stated his own opinions; consequently it was only necessary to refer him to the paper again.

Having had the opportunity of examining a comprehensive collection of oils from various horizons in Turner Valley, he could not accept Mr. Cunningham Craig's views concerning downwards migration and filtration of the oil. There was not space to quote details, but he suggested that a chemist might settle the matter one way or the other by analysing these samples and publishing the full facts in detail.

Concerning the Fort Norman oil he accepted the statements of those authorities who had examined the area, and they appeared to have no doubt that the origin of the oil was not later than Devonian. The facts would be found in the literature cited.

Dr. Lees had referred to the structural interpretation of Turner Valley by Dr. Link and Mr. P. D. Moore. He (Dr. Goodman) considered that the process postulated could be compared with a glacier meeting a ridge of hard rock lying across its path. According to Dr. Link's view, the glacier

sheared off the top of the ridge, but he (Dr. Goodman) thought it would glide over the top of it. In his own opinion the thrust fault beneath Turner Valley sprung from the Limestone fold itself, and not from somewhere to the west of it. The two views seemed unrelated, and the truth could therefore hardly lie between them.

Dr. Goodman pointed out that there were at least three well-known examples of very light petroleum constituents in Palæozoic rocks in this region under conditions which apparently precluded a Mesozoic source. In face of this evidence it seemed hardly justifiable to say that the Palæozoic oil in this region was heavy and of asphaltic base, and therefore the Turner Valley wet gas must be Mesozoic in origin.

Dr. Lees was right in criticising his (Dr. Goodman's) statement that there is no oil beneath the main thrust plane in Turner Valley. This statement should have been qualified. Reference to the paper would show that he (Dr. Goodman) did not regard this question of oil beneath the main fault as of any great importance, as he was quite ready to admit that some of the oil may be Mesozoic in origin. Objection to a Mesozoic source for the wet gas in Turner Valley was based upon petrographical evidence, regional evidence, the inter-relation of wells in Turner Valley, and the valuable information contributed by Perry from the Kevin–Sunburst Field. Such evidence was in his opinion of far more value than long-range comparisons or generalisations. If, in fact, a reservoir of crude oil still existed in Turner Valley, he thought that it was much more likely to be on the western flank in the Palæozoic Limestone than in Mesozoic rocks beneath the main fault. Personally he believed that the crude had been dissipated or expressed into the overlying Mesozoics in the manner suggested in the paper.

Dr. Goodman wished to thank Mr. Campbell Hunter for assistance in many ways during the preparation of the paper. He had heard many opinions concerning source rocks in Western Canada, based sometimes on field evidence, and sometimes on the vaguest generalisations. He believed that the time had come when these opinions ought to be tested from a new angle by collecting more evidence. There were plenty of samples available, and these should be tested petrographically and chemically.

He would like to suggest to Professor Illing that the apparent overstressing of the case for the Palæozoic origin of the oil was really due to understating the case for Mesozoic oil. When the present paper was read alongside the other papers in which the case for the Mesozoic origin of oil had been rather overdone in the past, he felt that a truer perspective would be possible.

From the literature concerning the Rocky Mountain thrust sheets in the United States and in Canada, he concluded that where over-thrusting of any considerable extent had taken place there was good evidence that the fault surface was in many cases a former land surface. This agreed with his own observations in the Crows Nest Pass and on the Ghost River. It should not, however, be assumed that no great forward movement is possible except along a land surface. It appeared that these big overthrusts were initiated as overfolds, and passed into reversed faults before emerging and going forward along a low angle surface. It appeared that the Turner Valley movement had gone a little beyond the reversed fault

stage, and had already commenced its career as a thrust block. With a little more push it would probably have emerged at surface as the other big overthrusts did. He agreed with Professor Illing that the difference of competency of the various rocks caused many of the minor structural differences noted in the Mesozoics.

The evidence which Mr. Von Weymarn quoted from his Clearwater well is important, and the more so because it came from an authoritative source. Further comment on his interesting contribution was unnecessary, as Mr. Von Weymarn had effectively dealt with the points he raised.

In replying to Mr. Owen's written contribution, Dr. Goodman agreed that the title was not as satisfactory as could be wished, but it was perhaps permissible to misquote the old parliamentary reply, "If the member will tell me another name which would be sanctioned and appropriate the author would be pleased to use it."

The source rock question had been discussed elsewhere, and the information from the Ranchmen's well, although of interest and importance, did not in his opinion affect the issue as far as the Turner Valley wet gas was concerned.

Dr. Hume, in a private communication, had stated that both he and others had come to the conclusion that the Silurian and Ordovician rocks reported from the Commonwealth Milk River well do not exist there, and the Devonian rests directly on the Cambrian at this locality.

On two main points Mr. Calder expresses the opinion that the general evidence is insufficient to justify the drawing of reasonable conclusions. No specific evidence or argument used in the paper has been criticised. The assumption that absolutely nothing is known concerning geological conditions beneath large areas of the Plains, because outcrop evidence is lacking, appears to under-estimate the possibilities of geological reasoning. There are very good reasons for believing that the Laramide Revolution produced little if any folding or faulting in the rocks of the Plains, as these form only a thin cover on the rigid basement rocks of the Canadian Shield. It is, however, true that very little direct evidence is so far available to show if Pre-Laramide folds occur in Palæozoic rocks beneath the Plains. Mr. Calder's assumption that structures (? folding and/or faulting) must occur at depth requires some supporting evidence before it finds acceptance.

Concerning the title of the paper, it is true that most of the detailed evidence has come from the Turner Valley area, and although only certain relevant aspects of the evidence from other areas has been considered (for full details of these areas reference should be made to the works cited in the bibliography) the title used, in the Author's opinion, covers the subject matter of the paper more adequately than the one suggested by Mr. Calder.

It is doubtful if methane or wet gas are necessarily indicators of a vast common oil source. Methane can be formed from a great variety of raw materials, and in the escape of petroleum from seepages it cannot be assumed that the lighter constituents are invariably dissipated first. There are cases, Turner Valley, for example, where the reverse may have happened.

The evidence and the arguments in support of a Palæozoic source for

the Turner Valley oil and gas has been put forward by the Author as self-supporting. It is local evidence, but there are plenty of indications that conditions were uniform over a large area. The better interpretation of conditions both east and west of Turner Valley would undoubtedly be useful for many purposes and might help in the determination of the source rocks of the oil and gas, but it does not appear to be a sine qua non in this connection.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

ANNUAL REPORT OF THE COUNCIL, 1934.

THE Twenty-First Annual Report of the Council covering the activities of the Institution during 1934 is presented for the information of the members.

MEMBERSHIP.

The following Table shows the alterations in membership which have occurred during the year, and the total membership on December 31st, 1934.

	Total Dec. 31, 1933.	CHANGES DURING 1934.							Total Dec. 31, 1934.
		New.	Transferred to.	Resigned.	Deceased.	Removed.	Transferred from.	+ −	
Hon. Mems. .	22	1	—	—	1	—	—	nil	22
Members .	582	38	16	10	7	9	—	+28	610
Assoc. Mems.	460	38	14	8	—	10	16	+18	478
Students .	99	32	—	5	—	5	12	+10	109
Associates .	87	7	—	3	—	2	2	nil	87
TOTALS .	1250	116	30	26	8	26	30	+56	1306

In addition to the above, on December 31st, 1934, 6 Members, 6 Associate Members and 2 Associates had been elected, but had not yet ratified their election, and 35 candidates were awaiting election.

This total membership of 1306 is the highest which has been recorded during the 21 years existence of the Institution.

The Inaugural General Meeting was held on March 3rd, 1914. It is gratifying to record that, at the coming-of-age of the Institution, the curve of growth of membership again shows an upward trend.

The Council have to record with deep regret the deaths of The Rt. Hon. Lord Greenway of Stanbridge Earls (President of the Institution, 1917–1919); Sir William Hardy, F.R.S. (Honorary Member); and of the following Members: S. Bowman, Dr. J. T. Erb, W. A. Guthrie, Wallace McMullen, R. A. Parnell and R. E. Way.

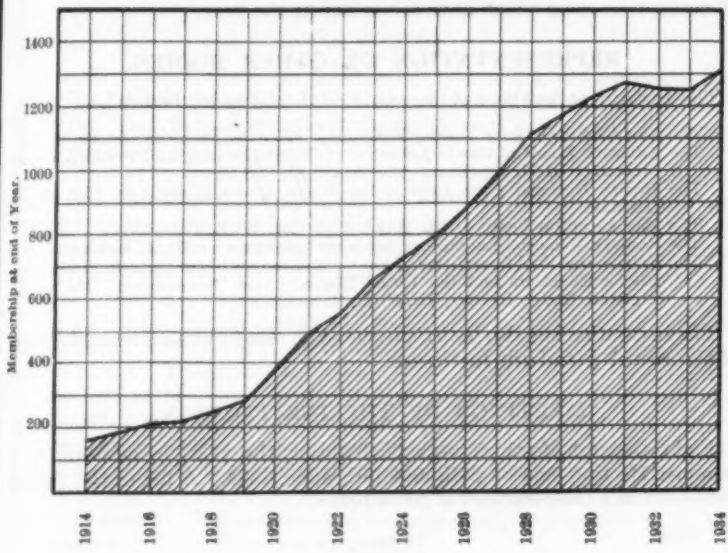
Dr. David White (Redwood Medallist, 1934) has been elected a Life Honorary Member of the Institution.

His Majesty has conferred the honour of K.C.B. upon Engineer Vice-Admiral H. A. Brown (Honorary Member).

Sir John Cadman, G.C.M.G. (President 1916–1917 and President-Elect), has been appointed a Member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research, and has been elected Hon. LL.D. of the University of Birmingham and D.Eng. of Melbourne University.

Sir Thomas Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S. (President 1925–27), has been elected Hon. LL.D. of the University of St. Andrews.

GROWTH OF MEMBERSHIP, 1914–1934.



ACCOUNTS.

The Accounts for the year ended 31st December, 1934, together with the Balance Sheet on that date, are presented.

Several items on the expenditure side of the Revenue Account are higher than in previous years. This is due to the increased activities of the Institution and the occurrence of certain items of expenditure of a non-recurrent character. The increased income from subscriptions is a gratifying feature of the accounts, as well as the amount of subscriptions previously written off now recovered, which appears on the Balance Sheet. The latter is indicative of the number of members who have been able to resume active membership of the Institution.

The Scholarships awarded by the Institution at the Royal School of Mines and at Birmingham University have been provided for in the Accounts, and it has been decided to continue the awards in 1935.

BENEVOLENT FUND.

In February 1934 the Chairman of the Benevolent Fund Committee addressed an appeal to all members of the Institution asking for their support of the Fund. Particular stress was laid upon the value to the Fund of regular annual contributions, however small in amount, and of collective subscriptions from Branches, laboratories, offices, etc.

The Council is pleased to be able to report that, largely as a result of this appeal, there has been an increased support of the Fund.

The thanks of the Council are tendered to all members who have contributed to the Fund, and in particular to the members of the Trinidad, Persian and South Wales Branches for their generous donations.

The Benevolent Fund Committee have been able to deal promptly with all necessitous cases which have arisen during the year.

REPRESENTATION ON OTHER BODIES.

The Institution has been represented on the following bodies :—

The American Society for Testing Materials. Dr. A. E. Dunstan and Mr. G. Sell.
The Advisory Board of the Department of Oil Engineering and Refining of the University of Birmingham. The President.
The British National Committee of the World Power Conference. Dr. A. E. Dunstan.
The Mechanisation Board of the War Office. Dr. W. R. Ormandy.
The Ramsay Memorial Laboratory Advisory Committee. Mr. J. Kewley.
The Engine and Fuel Committee (Joint Committee with the Institution of Automobile Engineers and the Diesel Engine Users' Association). Dr. A. E. Dunstan, Mr. J. Kewley, Dr. F. H. Garner.

The Institution has also been represented on many Committees and Panels of the British Standards Institution.

MEETINGS OF THE INSTITUTION.

Eight General Meetings were held during the year, in addition to a Summer Meeting held on 28th and 29th June, 1934. A list of the Papers presented and their Authors is given below.

Date.	Subject.	Author.
9th Jan.	"Oxidation Lubrication, and Blending of Mineral Oils."	R. O. King.
13th Feb.	"Chemical Evidence for Low-temperature History of Petroleum."	B. T. Brooks, Ph.D.
13th March.	Presidential Address: "The World's Petroleum Resources."	T. Dewhurst, A.R.C.Sc.
10th April.	"Surveying of Deep Boreholes."	Capt. W. E. Bruges, M.Sc., A.M.Inst.C.E.
8th May.	"Lubricating Grease."	H. S. Garlick.
9th Oct.	"Drilling against High Rock Pressures."	C. E. Keep, M.Sc., and H. L. Ward.
13th Nov.	"Petroleum Products as Horticultural Spray Materials."	H. Martin, D.Sc., F.I.C.
11th Dec.	"Utilisation of Paraffin Wax and Petroleum Ceresin."	P. G. Higgs, B.A.
	Papers Presented at the Summer Meeting.	
28th June.	"Oil and Coal, from the Viewpoint of the Petroleum Industry."	C. Dalley, M.I.E.E.
" "	"The Advantages of Expressing Liquid Petroleum Products in Terms of Volume."	J. McConnell Sanders, F.I.C.
" "	"The Format of the *Journal*."	G. Sell.
29th June.	Annual Reports on the Progress of Naphthology.	Various.

The Summer Meeting of June 1934 was an innovation designed to afford members of the Institution on leave in this country during the summer an opportunity of meeting their fellow-members, and of discussing the Annual Reports on the Progress of Naphthology.

The Sixteenth Annual Dinner was held at the Park Lane Hotel on Friday, June 29th, as part of the programme of the Summer Meeting, and was attended by about 200 members and guests.

PUBLICATIONS.

The Journal.

Vol. XX of the *Journal* was published in twelve monthly parts, and contained 16 Papers read at General Meetings of the Institution or at Meetings of the Branches, 24 contributed articles, the Annual Reports on the Progress of Naphthology, and the monthly Abstracts Section.

The Annual Progress Reports in the May and June issues of the *Journal* comprised 29 sections, including for the first time Regional Reports and a review of the year's Petroleum Literature. The thanks of the Council are tendered to the members and others who undertake the collection and compilation of these comprehensive surveys of developments in current petroleum technology.

The Abstracts Section contained 1662 Abstracts of Articles and patent specifications, an increase of more than 25 per cent. over the corresponding figure of 1933. The Abstracts have also been issued in leaflet form, printed on one side of the paper only, for indexing purposes. This facility is particularly commended to libraries and information bureaux.

Format of the Journal. At the Summer Meeting in June 1934 an opportunity was given to members to discuss the pros and cons of a change in size, in connection with a Paper on the subject presented by Mr. G. Sell, Associate Editor. The question has also repeatedly received the attention of the Council and various Committees.

After very careful consideration of cost, convenience, and other relevant factors, it was decided that the size of the page should be enlarged to 9 inches × 6 inches. This format was introduced with the issue of January 1935.

Proceedings, World Petroleum Congress.

The Proceedings of the World Petroleum Congress held in July 1933 were published in the early part of 1934 in two volumes and nine sectional parts. Vol. I contained the Geological and Production Sections and Vol. II the Refining, Chemical, and Testing Sections. The 242 Papers included in these Proceedings constitute one of the most important contributions to the literature of petroleum technology in recent years, and the volumes have been given a very gratifying reception in all parts of the world.

The thanks of the Council are due to Dr. A. E. Dunstan, D.Sc., F.I.C., and Mr. G. Sell, M.Inst.P.T., Joint Editors of the Proceedings.

STANDARDIZATION.

Chemical Standardization. The Chemical Standardization Committee had hoped to issue the third edition of "Standard Methods of Testing Petroleum and its Products" during 1934, but this was found impossible. By the end of the year, however, the work was practically complete, and the new edition is now in the hands of the printers.

Engineering Standardization. During the year the functions and work of the Engineering Standardization Committee were brought to the notice

of the leading oil companies, from whom a considerable measure of support was obtained.

The principle was followed of inviting nominees from the companies to join technical sub-committees of the Engineering Standardization Committee. Two such sub-committees were formed during the year dealing respectively with Pipes and Pipe Fittings, and Oil Well Cement.

The Oil Well Cement Sub-Committee, in co-operation with the British Standards Institution, prepared and circulated a questionnaire to the engineering departments of oil companies and to the Branches of the Institution overseas, with the object of obtaining information on the qualities of a satisfactory cement for oil well operations. The replies to this questionnaire are now being collated, and it may be possible to publish a Report covering the general conclusions at a later date. The thanks of the Council are due to those companies which placed their information on this subject at the disposal of the Committee.

LIBRARY.

The number of books issued on loan from the Library increased considerably in 1934, as compared with 1933. A large number of members also made use of the Library by personal visits, by correspondence, or by telephone.

AWARDS AND SCHOLARSHIPS.

The Redwood Medal was awarded to Dr. David White of the U.S. Geological Survey. The Medal was presented on the occasion of the Annual Dinner, and in the unavoidable absence of Dr. David White was received on his behalf by the First Secretary of the American Embassy.

The Student's Medal and Prize was awarded to Mr. G. D. Hobson (Royal School of Mines) for a Paper on "Some Viscometric Measurements of Clay Suspensions."

The two Institution Scholarships, tenable at the University of Birmingham and the Royal School of Mines, have been awarded to Mr. E. G. Stibbs and Mr. A. J. Haworth respectively.

RESEARCH FUND.

The Research Fund Committee has made grants during the year in assistance of the following investigations:

"Steels for Use at High Temperatures"; to the British Electrical and Allied Industries Research Association.

"The Correlation of Redwood and Kinematic Viscosities"; to the National Physical Laboratory.

"The Interaction of Acetylene and Boiling Sulphur; the Isomeric Thiophthens"; to Prof. F. Challenger, University of Leeds.

OFFICERS FOR SESSION 1935–36.

Sir John Cadman, G.C.M.G., Hon.LL.D., D.Sc., has been unanimously elected President for the Session 1935–36, and will take office at the conclusion of the Annual General Meeting.

Lt.-Col. S. J. M. Auld, Mr. Ashley Carter, Mr. C. Dalley, Prof. A. W. Nash, Mr. J. McConnell Sanders and Dr. F. B. Thole have been elected Vice-Presidents.

BRANCHES.

The Council is pleased to record that the Branches of the Institution in S. Wales, Trinidad, Rumania and Persia continue in active progress, and are well supported by members of the Institution resident in those countries. Five Papers presented before the Trinidad Branch have been subsequently printed in the *Journal*.

STUDENTS' SECTION.

The year was marked by considerably increased activity in the Students' Section of the Institution. The Committee of the London Branch organised a very successful meeting in May 1934, when Mr. T. C. J. Burgess gave an address on "The Economics of the Petroleum Industry."

The thanks of the Council are also tendered to Mr. Burgess for his generous donation of £30 to the Students' Prize Fund.

The Council desire to tender their thanks to the following for services rendered to the Institution: Lord Plender, G.B.E., Honorary Treasurer; Messrs. Ashurst, Morris, Crisp & Co., Honorary Solicitors; Messrs. Price, Waterhouse & Co., Auditors; and the Staff of the Institution.

The Auditors retire and, being eligible, offer themselves for re-election.

By Order of the Council.

ARTHUR W. EASTLAKE,
Honorary Secretary.

The Institution of

REVENUE ACCOUNT FOR THE

Dr.

	£ s. d.	£ s. d.
To Salaries		982 0 0
„ Rent, Rates, etc.		441 19 0
„ Printing and Stationery		220 12 11
„ Postage		311 1 8
„ Expenses of Meetings, including Hire of Hall...		208 13 3
„ Journals and Publications :—		
Expenses...	2145 0 4	
Less : Sales and Advertisement Revenue	1532 1 4	
		612 19 0
„ Grants to Branches		27 13 6
„ Sundry Expenses		304 2 10
„ Students' Prizes Scholarship Fund		80 0 0
„ Depreciation of Office and Library Furniture and Library Books		59 10 0
„ Library Expenditure :—		
Purchase of Books, Journals, etc.		30 8 3
„ Students' Section		45 9 9
„ Auditors' Fee		10 10 0
		£3335 0 2

STUDENTS' PRIZE AND

1934		£ s. d.
Dec. 31	To Scholarships Granted	80 0 0
	„ Balance Carried Forward	35 0 0
		£115 0 0

RESEARCH

1934		£ s. d.
Dec. 31	To Grants for Research	155 13 2
	„ Balance Carried Forward	351 3 9
		£506 16 11

Petroleum Technologists

YEAR ENDED 31ST DECEMBER, 1934. Cr.

	£ s. d.	£ s. d.
By SUBSCRIPTIONS :—		
Members	3115 15 9	
Special	20 0 0	
		3135 15 9
„ INTEREST AND DIVIDENDS, less Tax		132 5 11
„ BALANCE, being EXCESS OF EXPENDITURE over INCOME for the YEAR carried to BALANCE SHEET		66 18 6
		£3335 0 2

SCHOLARSHIP FUND.

1934		£ s. d.
Jan. 1	By BALANCE BROUGHT FORWARD	5 0 0
	„ T. J. C. BURGESS PRIZE	30 0 0
	„ REVENUE ACCOUNT	80 0 0
		£115 0 0

FUND.

1934		£ s. d.
Jan. 1	By BALANCE BROUGHT FORWARD	496 15 11
	„ INTEREST AND DIVIDENDS, less TAX	10 1 0
		£506 16 11

BALANCE SHEET AS

	£ s. d.	£ s. d.	£ s. d.
CAPITAL OF THE INSTITUTION under Bye-Law Section 6, paragraphs 14 and 15 :—			
Life Membership Fund—			
As at 31st December, 1933		624 0 0	
Entrance Fees—			
As at 31st December, 1933	2357 4 0		
Additions during year	153 6 0		
		2510 10 0	
Profit on Sale of Investments—			
As at 31st December, 1932		3 2 6	
Donations—			
As at 31st December, 1928		326 5 0	
			3463 17 6
STUDENTS' PRIZE AND SCHOLARSHIP FUND ...			35 0 0
RESEARCH FUND			351 3 9
MEMBERS' SUBSCRIPTIONS RECEIVED IN ADVANCE			135 15 0
JOURNAL SUBSCRIPTIONS RECEIVED IN ADVANCE			381 4 1
SUNDRY CREDITORS :—			
General Account		223 7 10	
Research Fund		17 15 0	
			241 2 10
REVENUE ACCOUNT :—			
Balance as at 31st December, 1933 ...		888 8 7	
Less : Subscriptions 1933, now written off		14 17 6	
		873 11 1	
Add : Subscriptions previously written off now recovered		138 1 0	
Grants in former years to Persia Branch refunded		150 0 0	
		1161 12 1	
Less : Deficiency for year as per separate account		66 18 6	
			1094 13 7
			£5702 16 9

Members of Council { T. DEWHURST. C. DALLEY.

AUDITORS'

We report to the Members of THE INSTITUTION OF PETROLEUM TECHNOLOGISTS and have obtained all the information and explanations we have required. We are correct view of the state of the Institution's affairs at 31st December, 1934, accord- by the books of the Institution.

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.
14*th February*, 1935.

AT 31ST DECEMBER, 1934.

	£	s.	d.	£	s.	d.
INVESTMENT AT COST :—						
On Account of Capital :—						
£1250 0 0 3½% War Loan	1196	18	6			
650 0 0 3½% Conversion Loan	505	7	0			
664 6 6 London County Council 3% Consolidated Stock	481	10	6			
150 0 0 Birmingham Corporation 6% Stock 1936/46	146	16	0			
100 0 0 Wigan Corporation 5% Redeemable Stock	99	14	11			
300 0 0 5% Conversion Stock 1944/64	336	4	6			
150 0 0 Wandsworth & District Gas Co. 5% Debenture Stock	154	8	6			
400 0 0 Metropolitan Water Board 3% A Stock	346	10	7			
125 0 0 Great Western Railway 5% Consolidated Preference Stock	105	4	9			
				3372	15	3
(Market Value at 31st December, 1934, £4105 3s.)						
On Account of Revenue :—						
£800 3½% War Loan	810	15	9			
On Account of Research Fund :—						
£350 3½% War Loan	358	16	9			
				1169	12	6
(Market Value at 31st December, 1934, £1250 12s. 6d.)						
OFFICE AND LIBRARY FURNITURE (excluding Presentations) :—						
As at 31st December, 1933	410	0	9			
Less : Sale of Typewriter	2	0	0			
	408	0	9			
Less : Depreciation	41	0	0			
				367	0	9
LIBRARY BOOKS (excluding Presentations) :—						
As at 31st December, 1933	74	0	3			
Less : Depreciation	18	10	0			
				55	10	3
MEMBERS' SUBSCRIPTIONS OUTSTANDING :—						
Estimated to Produce				63	0	10
SUNDRY DEBTORS AND PAYMENTS IN ADVANCE :—						
Sundry Debtors, less reserve for doubtful accounts ...	151	11	2			
Payments in advance	55	4	5			
				206	15	7
CASH AT BANK AND IN HAND				131	11	8
CASH ON DEPOSIT WITH BANKS :—						
General Account	300	0	0			
Research Fund	36	9	11			
				336	9	11
				£5702	16	9

REPORT.

that we have examined the above Balance Sheet with the books of the Institution of opinion that such Balance Sheet is properly drawn up so as to exhibit a true and ing to the best of our information and the explanations given to us and as shown

PRICE, WATERHOUSE & CO.

BENEVOLENT FUND.

RECEIPTS AND PAYMENTS ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1934.

RECEIPTS.

	£	s.	d.	£	s.	d.
BALANCE AT BANK ON CURRENT AND DEPOSIT ACCOUNTS, 1ST JANUARY, 1934				816	5	6
DONATIONS	97	8	7			
SUBSCRIPTIONS	18	19	0			
				116	7	7
INTEREST ON DEPOSIT ACCOUNTS				11	12	1
				£944	5	2

PAYMENTS.

	£	s.	d.	£	s.	d.
GRANTS IN AID				193	10	0
CHEQUE STAMPS					8	8
BALANCE AT BANK ON CURRENT AND DEPOSIT ACCOUNTS, 31ST DECEMBER, 1934, viz.:—						
Specific Endowment Fund	258	5	8			
Benevolent Fund Account	492	0	10			
				750	6	6
				£944	5	2

We have examined the above Receipts and Payments Account with the books and vouchers of the Fund and find it to be correct.

3, FREDERICK'S PLACE,
OLD JEWRY, LONDON, E.C. 2.
14th February, 1935.

PRICE, WATERHOUSE & Co.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

Annual General Meeting.

The Twenty-second Annual General Meeting of the Members of the Institution was held at the House of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Tuesday, March 12th, 1935, **Mr. T. Dewhurst,** President, in the Chair.

The Secretary read the Notice convening the meeting and the Auditors' Certificate.

The Minutes of the 21st Annual General Meeting, held on March 13th, 1934, were read, confirmed and signed.

Report of Ballot for Council.

The Secretary reported that six nominations had been received to fill five vacancies on the Council, and that as a result of the ballot the following members had been elected: Messrs. A. F. Dabell, T. R. H. Garrett, Prof. V. C. Illing, Dr. E. R. Redgrove, Mr. C. W. Wood.

New Members.

It was agreed that the list of Honorary Members, Members, Associate Members, Students and Associates elected and transferred during 1934 should be laid on the table.

Annual Report of Council, 1934.

The President said he had pleasure in submitting for approval the Annual Report of the Council, and also the Accounts for the year ended December 31st, 1934, together with the Balance Sheet at that date. Copies of these had been distributed to all members present and, with their approval, would be taken as read.

It was, he said, an honour and a source of much satisfaction to him to represent the Council at the present Annual General Meeting, as he was in a position to know and to appreciate the value of the services rendered by the Council—each and every member of which was wholeheartedly devoted to the interests of the Institution, and spent much time and effort in its service. The Table at the commencement of the Report showed a satisfactory growth of membership during the year. In no class was there any decrease in the number of members, while several classes showed satisfactory increases. The net result of the changes during the year was an increase in the membership of 56, while the total of 1306 members was the highest recorded in the history of the Institution. As a matter of interest, he would add that the membership at the moment was 1323. (Applause.) He particularly invited attention

to the Membership Chart, which showed a strikingly high rate of growth. Even the great economic depression, unexampled in depth and severity, was represented on the Chart by only a shallow, temporary dip of the curve. Moreover, even the most pessimistic extrapolation of that curve could not do other than indicate enormous future growth in membership. These points alone were sufficient to show the inherent strength of the Institution and to indicate its great destiny.

The Accounts for the year, and the Balance Sheet at December 31st, 1934, would be fully explained by Mr. Dalley, the Chairman of the Finance Committee, and he was confident that Mr. Dalley would be able to show that the net result was satisfactory, and reflected credit on all concerned. Personally, he would merely point out that several non-recurring items of expenditure had been incurred during the year, and that several economies had been instituted, the full results of which would be shown only in the Revenue Accounts of future years.

Scholarships at the Royal School of Mines and at Birmingham University had been awarded during the year. These scholarships had been awarded for the past eleven years, and their total good effect must already have been very considerable. Members would not be surprised to learn that it had been decided to continue the Awards in 1935. Indeed, these Awards were so essentially a function of the Institution, that it might safely be predicted that the only change in the future was likely to be in the nature of increases in the number and value of the Awards.

The Benevolent Fund of the Institution had been founded through the efforts of Dr. Dunstan, the Chairman of the Benevolent Fund Committee, and the generous response of members to Dr. Dunstan's appeal in February of last year had been most gratifying. He would like to stress the paragraph in the Report which stated that the thanks of the Council were tendered to all members who had contributed to the Fund and, in particular, to the members of the Trinidad, Persia, and South Wales Branches for their generous donations.

During the year the Institution had been represented on a number of important bodies, and it was satisfactory that, in this way, the participation and advice of members of the Institution continued to be much sought after and appreciated.

Eight General Meetings had been held during the year, and papers covering a wide range of subjects had been read and discussed. The first Summer Meeting of the Institution had been held in June of last year, and had been arranged mainly to give overseas members on leave in this country an opportunity of attending the Annual Dinner, and to enable the annual reports on the progress of naphthology to be discussed by members fresh from oilfields and refineries situated in various parts of the world. The results had been sufficiently promising to encourage the Council to repeat the experiment, and this year the Summer Meeting and Annual Dinner would be held on the last Friday in June.

The Report gave particulars of Vol. 20 of the *Journal*, which had been published during 1934, and members would agree that it maintained the high standard set by its predecessors. The Hon. Editor was, of course, responsible to the Council for the production of the *Journal*. Members would appreciate that a monthly issue entailed an enormous amount of

work, and during the later part of the year the machinery governing its production had been overhauled and the detailed work carefully apportioned between the Secretary, the Associate Editor, and Mr. Noble. The Abstracts section of the *Journal* testified to the very large amount of painstaking and valuable work which was ably carried out by the Abstract Sub-Committee under the chairmanship of Dr. Garner. In regard to the annual reports on the progress of naphthology, he would specially direct attention to the sentence in the Report which stated that the thanks of the Council were tendered to the members and others who had undertaken the collection and compilation of these comprehensive surveys of developments in current petroleum technology.

The format of the *Journal* had been the subject of very thorough investigation during 1934, and towards the end of the year the present form had been decided on by the Council. He was sure that members would welcome the larger format for the 21st volume as being expressive of the more mature status which the Institution had now attained. He would direct attention to the statement in the January number of the *Journal* that the Council and Publication Committee were desirous only of providing a *Journal* which met with the general approval of the members, and would welcome any expression of opinion on the new format, or any suggestion for the further improvement of the *Journal*. He urged members to read the Institution Notices in the *Journal*, as an effort was being made to make this section increasingly interesting and useful to members. He would particularly mention that notices of future meetings of the Institution were given on page iv of this section.

Members were familiar with the proceedings of the World Petroleum Congress, and he thought it was permissible on the present occasion to point out that the printing charges had amounted to a very considerable sum, and that, despite pessimistic expressions of opinion and adverse reports regarding the sale of the proceedings of certain other congresses, the Council had nevertheless taken the bold step of sanctioning this large expenditure; he was very glad to be able to report that this bold policy had already been entirely successful and justified by the large demand for copies from all parts of the world. This result was in keeping with the record of successes which the Congress had met with at every stage from its inception.

The work carried out by the Chemical and Engineering Standardization Committees was summarised very briefly in the Report. It was impossible in an annual report to do justice to the large amount of accurate detail and valuable work carried out by the two Committees and their respective sub-committees. Members would appreciate the fact that Professor Brame had been identified with the work of the Chemical Standardization Committee since its inception, and had been Chairman of the Committee for some years. The work carried out by this Committee was very widely appreciated, and in this connection he was pleased to be able to report that the Third Edition of "Standard Methods of Testing Petroleum and its Products" was awaiting the final approval of the Committee, and the book should be ready for issue about the end of April. This edition had been eagerly awaited for some considerable time, and would undoubtedly maintain, and even enhance, the high reputation built up by the two

previous editions. The Engineering Standardization Committee was comparatively new, but, under Lieut.-Colonel Auld, was losing no time in establishing a wide and important sphere of usefulness.

The Library continued to be increasingly appreciated, the Librarian receiving many requests for information on all aspects of petroleum technology. The number of such consultations during the year had been about 1000, which showed the value of the Library to the members.

The Branches of the Institution in Trinidad, Rumania, Persia, and South Wales had continued their activities during the year. As the Report stated, five papers read before the Trinidad Branch had been subsequently printed in the *Journal*. Members would have been gratified to learn that since the expiry of the year under review a Branch of the Institution had been formed in Burma, with a strong committee and list of officers. Members everywhere would echo the wish that the new Branch would have a long and prosperous future. ("Hear, hear.")

A strong and active Students Section was of vital importance to the future welfare of the Institution, and therefore it was pleasant to record that the year under review had been the most successful in the history of the Students Section. Thirty-two new students had joined during the year and, despite continual transfers to a higher grade of membership, the net increase in the number of students had been over 10 per cent. It was, of course, impossible to comment on this Section without referring to the great interest which Mr. Ashley Carter continued to take in all matters affecting the welfare of the students.

The furtherance of research in the various branches of petroleum technology was the most important function of the Institution, and therefore it was satisfactory that the Report recorded several investigations which had been assisted during the year by grants from the Institution's Research Fund. The Council, rightly, attached great importance to this aspect of its activities, and wished it to be widely known that the Research Fund Committee would give applications for grants in aid of suitable items of research every consideration.

It gave him much pleasure to refer to the excellent work carried out by the staff of the Institution. The Institution had a busy and a happy staff, the members of which responded promptly and fully to the calls made upon them.

There was only one further comment to make in presenting the Report. The year 1933 had been unique and spectacular owing to the holding of the World Petroleum Congress, and it was inevitable that the activities of the succeeding year must appear tame and uninteresting by comparison. Nevertheless, he could assure members that during the year 1934 a very large amount of useful spadework had been accomplished. On the whole, it had been a period of seed time, and the full harvest would be gathered only in future years.

With this conception of the year's work prominently in mind, he commended the Report of the Council to the members' favourable acceptance, and formally proposed "That the Annual Report of the Council, and also the Accounts for the year ended December 31st, 1934, together with the Balance Sheet at that date, be and are hereby received and adopted," and he would ask Mr. Dalley to second the motion.

Mr. C. Dalley, Chairman of the Finance Committee, in seconding the motion, said he desired to comment on one or two points in connection with the Accounts. Reference had been made at the last Annual General Meeting to the fact that it was not always easy to make the expenditure fall within the limits of the revenue, and that in some years there might be a credit balance and in others there might be an adverse balance. Last year there had been a small credit balance. This year there was apparently an adverse balance of £66 18*s.* 6*d.* He said "apparently" because in actual fact there was a credit balance. If reference was made to the Balance Sheet, two items would be noticed: (1) "Subscriptions previously written off now recovered" totalling £138 1*s.* 0*d.*; and (2) "Grants in former years to Persia Branch refunded £150 0*s.* 0*d.*" If those two items were taken into the year's revenue, the Institution actually had a substantial credit balance, but as these were non-recurring items they could not appear in the annual Revenue Account.

The item "Expenses of Meetings" of £208 13*s.* 3*d.* showed an increase, which was due to the fee for hiring the hall having been considerably raised. The possibility of this increase had been forecast at the last Annual Meeting.

It would be noted that the item "Journals and Publications" was somewhat elaborated in the present Accounts, showing the gross cost of the *Journal* and also the amount of revenue by sales and advertisements.

The item "Depreciation of Office and Library Furniture and Library Books" had followed the lines of previous years.

Before leaving the Revenue Account there was one point he desired particularly to mention, and that was the Auditors' fee. Messrs. Price, Waterhouse & Co. had been the Auditors of the Institution since its inception, and for a number of years had acted in an honorary capacity. Later, and up to the present time, they had received a nominal fee of ten guineas. They now pointed out that this fee was entirely out of proportion to the work involved in auditing the Accounts of the Institution, with its present membership and activities. The question of revising the fee had been discussed with them and, subject of course to the agreement of the present meeting, the Auditors agreed to re-election provided their fee was increased from ten guineas to forty guineas.

Turning to the Balance Sheet, it would be seen that there was a very substantial appreciation in the value of the Institution's investments. The Finance Committee was obtaining the advice of Lord Plender, the Institution's Hon. Treasurer, with a view to the sale and re-investment of the Institution's securities, with the object of taking advantage of the appreciation in the value of the stocks.

The Finance Committee had during the year made several attempts to obtain relief from "Income Tax." Owing to technical difficulties in the Articles, this had so far proved impossible; but the Finance Committee were continuing the attack, and were making another effort very shortly.

He desired to add to what the President had already said regarding the Benevolent Fund. Although this Fund was receiving substantial support, there was still plenty of room for members to contribute, and so build up a Fund from which grants in aid could be made out of the interest, leaving the capital untouched.

He did not think there were any other points to which he desired to

direct particular attention. The Finance Committee had pleasure in submitting the Statement of Annual Accounts to the members which in their opinion could be regarded as satisfactory. He formally seconded the motion for the adoption of the Report and Accounts.

The President then inquired if any member desired to ask any question concerning the Report and Accounts.

Dr. J. A. L. Henderson said it was delightful to know that the Institution had been able to establish a Benevolent Fund and that it was being so ably administered, but he would like to ask whether the Fund was considered one of the direct functions of the Institution; in other words, whether it belonged to the organisation of the Institution, or was it a separate entity? He understood that the answer to the question might have some influence upon the matter of income tax.

The President replied that if Dr. Henderson would refer to the Memorandum of Association and read therein the objects of the Institution, he would find that one of those objects was the establishment of a Benevolent Fund. That was quite definitely one of the objects of the Institution, just as much as the holding of ordinary general meetings was an object of the Institution. He would ask Mr. Dalley to reply to the second part of Dr. Henderson's question.

Mr. Dalley said the second part of Dr. Henderson's question entirely depended on the way in which the Institution's Articles of Association had been drawn. It was the technical question of the first Article of Association which had proved so far the stumbling-block; but he was perfectly confident that, by continually keeping at the subject, they would get over the difficulty.

Dr. E. R. Redgrove remarked that in view of the small rate of interest which could now be obtained on deposit accounts, he would like to suggest to the Finance Committee that they should avail themselves of the 2½ per cent. offered by the Post Office. He understood that an amount up to £500 could be invested each year in that manner, and although the Institution might thereby render itself liable to a little more income tax, he thought it was well worth consideration.

The President replied that the point just raised was in fact now under discussion by the Finance Committee.

No other questions being raised, the motion for the adoption of the Report and Accounts was then carried unanimously.

Annual Reports of Students Section.

The Secretary then read the Annual Reports of the London and Birmingham Branches of the Students Section :—

LONDON BRANCH.

On December 31st, 1934, the Student Members of the Institution numbered 109, a net increase of 10 during the year. It is gratifying to note that this is the first increase

in membership which has been shown for the past four years, although the total is still under that of 1930.

In the London Area 12 new members were elected, 2 members were transferred to Associate Membership, 4 members had departed overseas and 9 members were awaiting election, making the total available membership of the London Branch 51. A very hearty welcome is extended to new members.

At the 11th Annual General Meeting, on February 6th, 1934, the following were elected to serve on the Committee :—

Messrs. A. S. Bridgwater, W. J. Gillingham, A. B. Cameron, R. H. Keach, A. J. Haworth, R. E. de Mestre, G. M. Barrett, and B. C. Ferguson.

Messrs. A. S. Bridgwater, W. J. Gillingham, and B. C. Ferguson were subsequently elected Chairman, Vice-Chairman, and Hon. Secretary respectively. Mr. W. J. Gillingham tendered his resignation later on going abroad, and Mr. G. M. Barrett was elected to his office.

Alterations to Rules 13 and 17 of the Section were made in order to facilitate the smooth working of the branches. The last paragraph of Rule 13 was altered to read : "The new Committee shall have its first meeting during the last month of the Session (as defined in Rule 7) and if convenient subsequent to the last meeting of the Branch." Rule 17 was altered to read : "The election of the Chairman, Vice-Chairman, and Hon. Secretary shall be made at the first meeting of the new Committee, to be held in no case later than May."

Ten meetings were held in 1934, at which the following events took place :—

January.	Mr. M. Abramovitch, "The Structural Significance of Gravitational Anomalies."
February.	Annual General Meeting followed by a paper by Mr. C. H. G. Hands, "Treatment of Lubricating Oils."
	Visit to Shell Haven, followed by the Annual Dinner.
March.	Mr. W. J. Gillingham, "The Theory of Oil Origin."
May.	Mr. T. C. J. Burgess, "The Economics of the Petroleum Industry."
October.	Mr. J. Kewley, "The Flexibility of the Petroleum Industry."
	Visit to the Fuel Research Station, Greenwich.
November.	Mr. A. B. Cameron, "Porosity and Permeability of Rock."
	Dr. G. M. Lees, "Oil Geology of Persia."
December.	Mr. G. D. Hobson, "Some Viscometric Measurements of Clay Suspensions."

A new departure during the year was the May meeting, when the Committee arranged a large meeting to which invitations were extended to the junior staffs of all the oil companies in London, and also to the students at the various technical schools and University Colleges in London. On this occasion it was considered advisable to arrange a paper of very general character, and Mr. T. C. J. Burgess very kindly consented to address the meeting.

The attendance was over 160, and has undoubtedly resulted in several new members joining the Section.

Following this success, it has been decided that this special meeting shall be made a permanent feature of the programme, and that a prominent member of the industry should be approached each year to give an address.

The Committee decided, when making arrangements for the session 1934–5, that the increased interest of the Branch warranted a more comprehensive programme, and additional meetings and visits were therefore arranged. A comparison of the meetings for the two sessions is as follows :—

	1933–4.	1934–5.
Visits	2	3
Student papers	3	6
Other papers	4	5
	9	14

Two entries for the Students' Medal and Prize were submitted from the London Branch. Mr. G. D. Hobson of the Royal School of Mines received the award for his paper "Some Viscometric Measurements of Clay Suspensions." The Committee would like to congratulate him on this success, and also Mr. A. J. Haworth on being awarded the R.S.M. Scholarship.

Due to the generosity of Mr. T. C. J. Burgess, a special prize of £10 will be awarded

annually during the next three years for a paper which is not restricted to a subject of technical character. It is to be hoped that this and the Institution's Students' Medal and Prize will attract a large number of entries from the London Branch.

The attendance of Students at meetings shows a small increase, but it is felt that there is still room for improvement. It is also gratifying to note that the number of visitors at these meetings has increased, and it is hoped that this will result in a further addition to the membership of the Section. The Committee feels strongly that more Students should participate in the discussions.

The second Annual Dinner, held on February 27th, at Stone's Chop House was very well attended. The Branch had the pleasure of entertaining two members of Council, and an enjoyable evening was spent by all.

Judging from the attendance, the visits still retain their position as the most popular item on the programme, and their importance cannot be too highly stressed.

The Committee wishes to express its appreciation of the interest shown in the Branch by senior members and of the help given by Council, and in particular by Mr. Ashley Carter. The executive officers are extremely grateful to the Secretary, Mr. S. J. Astbury, and his staff, for the willing assistance which they have always rendered to the Branch.

The practice of holding informal dinners after the meetings has been continued throughout the year. These have been generally well attended, and it is felt that they do a lot to bring the members of the Branch into more intimate contact with each other.

(*Signed*) B. C. FERGUSON,
Hon. Secretary, Students Section
(*London Branch*).

BIRMINGHAM BRANCH.

The Committee have pleasure in presenting the Twelfth Annual Report, for the year ended December 31st, 1934.

At the Annual General Meeting in March 1934 the following officers for this Branch were elected.

Mr. E. G. Stibbs (Chairman).
Mr. M. R. M. Porter (Vice-Chairman).
Mr. L. V. W. Clark (Hon. Secretary and Treasurer).
Messrs. E. R. Ward and Taylor (Committee).

During the year five meetings were held and the following papers read :

February.	"The Iraq Pipeline," by Dr. A. E. Dunstan.
March.	Annual General Meeting.
May.	"Corrosion in the Oil Industry," by Mr. F. R. Wellings.
	"Bubble Tower Design," by Mr. J. D. Hall.
October.	"Analysis of Oilfield Waters," by Mr. W. R. Wiggins.
November.	"Oil-Well Surveying, with particular reference to the Martienssen Apparatus," by Capt. W. E. Bruges, M.Sc.

The attendances throughout the year were somewhat lower than previous years, averaging 18 members and visitors, owing to a slight falling off in the number of members.

During the year the following excursions were made by the members of the Birmingham Branch :—

1. Coventry Colliery Co.
2. Bellis & Morcom, Ltd.
3. Tangyes Ltd.
4. Hamstead Colliery Co.

and the thanks of the Committee are tendered to the various companies concerned for their courtesy in allowing the visits to be made to their works.

(*Signed*) L. V. WOODHOUSE CLARK,
Hon. Secretary, Students Section
(*Birmingham Branch*).

The President said there would be general agreement that these reports recorded very satisfactory progress, and reflected great credit on the Chairman, the Hon. Secretary, and the Committee of each of the Branches.

Annual Reports of Branches.

The Secretary then read the annual reports of the Branches in Persia, South Wales, Rumania, and Trinidad as follows :—

PERSIAN BRANCH.

The Membership of the Persian Branch on December 31st, 1934, was as follows :—

Members	10
Associate Members	43
Students	9
Associates	7
	69

The Accounts for the years 1932, 1933, and 1934 are presented herewith.

During the year 1934 funds amounting to £150 were returned to the Parent Institution, as the Committee considered that the balance held was more than sufficient to cover the requirements of the Branch. After making the above payment, there was a credit balance on December 31st, 1934, of £71 19*s.* 2*d.*

Four Papers have been presented to the Branch during the year.

In May 1934 Mr. C. J. Wright, who had acted as Honorary Secretary of the Branch since its inception, was succeeded by Mr. C. V. Rutherford in the capacity of Honorary Secretary of the Branch.

E. C. Brewster,
Chairman,
Persian Branch.

RUMANIAN BRANCH.

The Committee have pleasure in presenting the Eighth Annual Report for the year ending January 31st, 1935, together with the accounts to that date.

Revenue Account for the year ending January 31st, 1935.

Credit.	Lei.	*Debit.*	Lei.
Balance on hand at Jan. 31st, 1934	547	To stamps and envelopes	240
Grant from London	2000	Printing	164
		Stationery and applications	160
		Expenses of Meetings	910
Total	2547	Total	1474
Balance in hand Lei	1073		

The Branch register shows the following list of Members :—

Honorary Members	1
Members	31
Associate Members	14
Students	1
Total	47

which is a decrease of 2 in the total compared with a year ago.

The Seventh Annual Meeting was held on Friday, January 26th, 1934, at which the chairman, Mr. J. L. Chaillet, retired, and was succeeded by Mr. I. Edeleanu. Also two members of the Committee retired in rotation, and offered themselves for re-election. Mr. E. C. Masterson was nominated to fill the vacancy caused by the retiring chairman becoming ex-officio member of the Committee. Messrs. Penny, Clark, and Masterson, were all elected without opposition.

Three General Meetings of the Branch were held during the year at which the following papers were read :—

January 26th, 1934.	41st General Meeting.	"Some Engineering Aspects of Natural Gas," by J. F. Hanst.
February 16th, 1934.	42nd General Meeting.	"Completion of Wells," by J. L. Chaillet.
November 2nd, 1934.	43rd General Meeting.	"Development of Wire-Rope Pumping," by P. R. Clark and L. Schropp.

The Eighth Annual Dinner was held on December 15th, 1934, under the Chairmanship of Mr. Edeleanu. 56 Members and visitors were present.

The Committee for the year consisted of :—

Messrs. Ion Edeleanu, Chairman.
J. L. Chaillet, ex-officio member.
J. E. Treacy, Treasurer.
F. W. Penny.
P. R. Clark.
C. M. Leitch.
E. C. Masterson.
C. R. Young, Honorary Secretary.

The Committee wish to record their thanks to the Chamber of Commerce, Ploesti, for the use of their hall for the meetings.

(*Signed*) C. R. YOUNG,
Hon. Secretary,
Rumanian Branch.

SOUTH WALES BRANCH.

The membership of the Branch under the new conditions has continued at a high level. During the Session three meetings have been held, with an average attendance of 50.

The papers have been of high standard, two of general and one of local interest. We were fortunate in securing Mr. Stansfield of the Anglo-Persian Research Staff to come and give us an account, at first hand, of the Conference held in America in connection with Engine Testing. A film of the Conference was shown, and the discussion indicated the intense interest taken by the Section in this subject.

In January we were able to secure Messrs. A. T. Barber and A. H. Taylor for a meeting held jointly with the Institute of Mechanical Engineers, and an extremely interesting and important paper was read on "High-Pressure Plant for Experimental Hydrogenation Processes." There was a good attendance at this meeting.

A record attendance was secured for the paper of local interest given by one of the Refinery Staff (Mr. E. S. Squire) dealing with "The Development of Refining Processes," at Llandardy.

On March 14th we are to have a visit from Lieut.-Col. S. J. M. Auld, who will speak about "Lubricating Oil from the Consumer's Point of View."

An Epidiascope was purchased, and it has proved extremely useful, and has helped considerably to maintain the very great interest shown by the members of the Section in the papers given during the Session.

(*Signed*) E. THORNTON,
Hon. Secretary,
South Wales Branch.

March 7th, 1935.

TRINIDAD BRANCH.

Annual Report for Year ended October 31*st*, 1934.

Six meetings were held during the year, at which the following papers were read :—

November 29th, 1933.	6th Annual General Meeting. "Some Malarial Problems in Trinidad and their Control," by Dr. E. J. de Verteuil.
January 31st, 1934.	36th General Meeting. "The Relation of Sub-surface Factors to Well-head Control in its Influence on Rate of Flow," by K. W. G. Patterson (Assoc. Member).
February 28th, 1934.	37th General Meeting. "Economics of Pumping and Gas Lift," by T. W. Dagg (Member).
March 28th, 1934.	38th General Meeting. "Absorption," by A. Newton.
May 9th, 1934.	39th General Meeting. By the courtesy of the United British Oilfields of Trinidad Ltd. a film was exhibited showing some experiments to illustrate the theory of Dr. Versluys. This was introduced by L. A. Toone (Member).
May 30th, 1934.	40th General Meeting. "Some Notes on Barytes Recovery from Muds," by G. H. Scott, B.Sc. (Assoc. Member).

The average number of members and visitors present at the meetings was 36.

At the end of the year under review there were 54 members on the roll of the Branch.

The Fourth Annual Dinner was held at the Queen's Park Hotel, Port-of-Spain, on October 27th, and was attended by 114 members and guests. The Branch was again honoured by the presence of His Excellency the Governor, Sir Claud Hollis, G.C.M.G., C.B.E.

The Committee desires to record with great regret the resignation of Mr. A. F. Dabell, who was instrumental in founding the Branch early in 1928, and who served continuously on the Committee from the inception, occupying the Chair for the first five years.

The Accounts for the year have been audited, and are presented below.

The Committee have great pleasure in recording the thanks of the Branch to the Auditors, Messrs. Middleton and Walsh, to the members of the Apex and Pointe-a-Pierre Clubs for the use of their rooms, and to the partners of the Fyzabad Empire for the use of their theatre and cinematograph projector.

(*Signed*) G. H. Scott, *Chairman*,
(*Signed*) H. W. Reid, *Hon. Sec. and Treasurer*,
Trinidad Branch.

SUMMARY OF ACCOUNTS FOR YEAR ENDING OCTOBER 31st, 1934.

Revenue Account.

To Stenographers' remunerations	$90.00	By Quarterly Grants from London	$115.20
,, Printing, Postage, Telephone, Stationery, and Sundries	39.76	,, Enrolment Fees	14.00
,, Drafts on London, Benevolent Fund $284.27 *Less* Subs. received 282.80	1.47	,, Deficit for the year	14.04
,, Loss on 4th Annual Dinner	12.01		
	$143.24		$143.24

Balance Sheet.

Revenue Account.	
Surplus brought forward as per last account	$37.01
Less deficit as per above account	14.04
	$22.97

(*Signed*) F. Middleton, D. M. Walsh } Auditors.

Presentation to Mr. A. Frank Dabell.

The President remarked that, as the Chairman of the Branch Committee, he had a knowledge of the working of the Branches, and was of opinion that the progress recorded in the reports just read was, on the whole, as satisfactory as could be expected in view of the difficult conditions which had obtained in many countries during 1934.

In regard to the report for the Trinidad Branch, members would have appreciated the tribute to the work of Mr. A. F. Dabell. The idea of establishing a Branch of the Institution in Trinidad had originated with Mr. Dabell, who had convened a meeting of those who were likely to be interested in the project. That meeting had been presided over by Sir Thomas Holland, who had been on a visit to Trinidad, and it had been unanimously decided to recommend to the Council that a Branch be

established. The Council had welcomed the project, and early in 1928 a Branch had been formed, with Mr. Dabell as chairman. Mr. Dabell had continued to act as chairman for the first five years of the Branch's existence, and had served continuously on the committee until his resignation towards the end of 1934. It had been very largely due to Mr. Dabell's efforts that the Trinidad Branch had been established on a thoroughly sound basis, and that it had continued to prosper since its inception. (Applause.) Members of the Branch had also expressed their appreciation in tangible form, as they wished Mr. Dabell to have a permanent token of their regard. They had chosen the beautiful electric clock which those present would see on the table, and they had asked him (the President) to present it to Mr. Dabell on their behalf. It was with the greatest pleasure that he undertook this duty, and in doing so he would stress the fact that, by hard work and unselfish devotion in a good cause, Mr. Dabell quite unconsciously had raised, in the formation of the Branch, a monument to his career in Trinidad. (Applause.)

Re-Election of Auditors.

Mr. A. P. Catherall proposed that Messrs. Price, Waterhouse & Company should be re-appointed Auditors for the ensuing year at a fee to be agreed upon.

Mr. L. P. Timmins seconded the motion, which was carried unanimously.

(The meeting was then thrown open to visitors.)

Induction of Incoming President.

The President remarked that when he had been inducted to the Chair two years ago, he had considered it to be his duty to acquaint members with his views regarding the Institution. Those views were recorded in the *Journal*, and there was little or nothing that could usefully be added to them at the present juncture. He would, however, stress the following sentence of that statement :—

> "It may confidently be predicted that, with an improvement in general conditions, we shall advance from strength to strength, and in regard to the permanent factors affecting petroleum technology we may rest assured that in the future science will be harnessed to industry even more closely and firmly than at present, and that our particular species will increase in usefulness, number, and variety."

He was still extremely optimistic regarding the future, for, notwithstanding the enormous advances which had been made since the Great War, it was certain that, taking the long view, research in the various branches of petroleum technology was still in its infancy.

One of the most encouraging incentives to work for the Institution was that the benefits which it could confer were proportionate to its size, strength, and success. The bigger, stronger, and more successful the Institution became, the more helpful it was to its members, to all petroleum

technologists, to the petroleum and related industries, and to cognate societies and institutions. No one had anything to lose, and everybody concerned had much to gain as a result of the further growth of the activities of the Institution.

Each and every Past-President had contributed something characteristic and unique to the growth of the Institution. However, in the case of a petroleum geologist, the gestatory process was so slow that a longer period than the ordinary term of office would be required to produce an average result. Although one could not judge one's own work, he thought he might claim to have been a constitutional President. He had given a little study to the Constitution of the Institution as laid down in the Memorandum of Association and the By-laws, and he was impressed with the soundness and with the wisdom of the provisions contained therein. Indeed, he was even a little proud of the fact there that had been no changes in the By-laws during his term of office, and he was firmly of the opinion that future changes should be made only after the closest possible scrutiny. Like every other President, he had given a little thought to the organisation of the Institution. The voluntary work had increased steadily in course of time, and was now very large. He was of the opinion that this work could best be carried out by means of a large Council with numerous small expert committees, each with its own separate chairman. The key positions in the organisation would therefore be the Presidency, the Hon. Secretaryship, and the Chairmanships of the various committees of Council.

During his term of office he had been deeply impressed with the spirit of helpfulness and of loyalty to the Chair, and he thanked most sincerely all the Past-Presidents, Vice-Presidents, and Members of Council who in this way had made his task a most pleasant one. In agreement they had been happy workers, and would have been happy warriors in case of difference. His thanks were particularly due to his immediate predecessor in the Chair, to the Hon. Secretary, to the Hon. Editor, and to the chairmen of the various committees of Council. It was they who had borne the heat and burden of the day, and their strength had increased with the burden and their cheerfulness with the temperature. He was also the only President who had had the advantage of working with the Secretary, and he would testify to the value of the Secretary's useful habit of delving into the Institution's records and statistics and producing orderly and suggestive reviews of its various activities.

In regard to his term of office, he had nothing more to say, for time was passing, and "in to-day already walks to-morrow." Indeed, he was left only with the hope that he passed on the sceptre untarnished and even undimmed.

The election of the President of the Institution was governed by the By-laws, Section 7, No. 3, which stated "The President shall be either a Member of the Council, a Vice-President, a Past-President, or Past-Vice-President." The view that the field of election of the President was restricted to the Vice-President was erroneous, and rightly so, as Vice-Presidents were elected primarily for the purpose of deputising for the President. That a Past-President might resume the Chair was now being demonstrated for the first time in the history of the Institution as being an exceedingly wise and fortunate provision.

He would not attempt the impossible task of giving the Institution's new President any information concerning the Institution, for, despite his many interests, members were inclined to regard the Institution as being Sir John's spiritual home. Neither would he attempt the equally impossible task of giving members of the Institution any new information regarding their new President. In these circumstances, therefore, he could only stress a few well-known points. The new President was a Founder Member of the Institution, and was its senior living Past-President, having been inducted to the Chair by the Institution's Founder and first President, Sir Boverton Redwood. Although Sir John had vacated the Chair in 1917 to take up national and international work of vital importance, he had since that time served uninterruptedly as a Member of Council, and had always maintained a great interest in the Institution's affairs, and had been ready to step in at any moment to help the Institution in its progress. Sir John had certainly rendered invaluable services to the Institution during his own term as President. Some years ago it had been the generally accepted view that all scientific research was carried out in the laboratories and the libraries of purely academic institutions, and that the resulting academic discoveries passed through a recognised series of stages leading to their final adoption by industry. It was now, however, widely recognised that many industries had themselves become scientific, and carried out their own scientific research. Indeed, scientific workers in industry did not so much apply academic discoveries as that they were themselves continuously engaged in original scientific work. Of the men who had effected this great change he did not know anyone who had been more prominent than had their new President. Indeed, of all the scientific men who had entered industry Sir John stood pre-eminent.

He would again stress the loyalty and the spirit of helpfulness which were shown to the Presidential Chair. Every Past-President, Vice-President, and Member of Council gave all the help possible to the President. Every officer of the Institution appreciated the fact that the new President had heavy and manifold duties and responsibilities and, he thought he might add, opportunities; and the fact that in these circumstances Sir John had agreed to resume the Chair afforded, he thought, the clearest and most convincing proof of Sir John's affection for the Institution and of his desire to serve its interests. It was clear, therefore, that the loyalty and the helpfulness to which he had alluded would be accorded to Sir John in the fullest measure.

The inaugural meeting of the Institution had been held in the present room on the 3rd March, 1914, which was just over 21 years ago. It was very gratifying that on the present occasion they had with them several members, including their new President, who had been at that inaugural meeting, and it was indeed fitting that Sir John, who had guided so well the footsteps of the infant Institution, should again be in charge of its destinies in the first flush of its maturity. Above all, it was most fitting that Sir John should be the Institution's President during this Jubilee year. (Applause.) Sir John's acceptance of the Presidency had given the greatest possible pleasure not only to the officers of the Institution, but also to all the members who were scattered in some fifty countries, and to the Institution's friends throughout the world. On their behalf he had

the greatest pleasure in inviting Sir John to resume the Presidential Chair.

Sir John Cadman took the Chair amid applause, and said that at first it was with feelings rather of diffidence that he had accepted the honour placed on him, but he was somewhat reassured when he realised that, after having occupied the presidency nineteen years ago, he would once again be taking a position which had given him so much pleasure in the past.

Passing on to deal with fragments of the very earliest history of the Institution, Sir John referred to the late Sir Boverton Redwood and their ruling honorary secretary, Mr. Arthur W. Eastlake—whom Sir John said he was so happy to have beside him again on the present occasion. Mr. Eastlake knew more about the foundation of the Institution than anyone else, and one day they hoped to persuade him to tell that interesting story. Sir John said he could testify that the Institution did not spring into being over-night, but was the result of deliberations spread over several years prior to the official inception, and he was glad to see present some of those early founders. He recalled the many and long deliberations in Sir Boverton's and Mr. Eastlake's offices, and the questions they had to ask themselves. Was the scheme possible? Could they find enough people in such a young industry and one which was linked with so many branches of science? Could they do anything which would set into motion an organisation which would bring all such persons together?

It was a great enterprise the founders of those days had undertaken, but it had achieved its aim and the results were obvious to-day in the membership, which they had just heard was now 1323—as compared with 200 when he previously occupied the Chair. The Institution had grown vastly in strength and influence, and he was delighted to occupy the Presidential chair once again.

Sir John said he had been called on in those early days to stimulate the educational side of the Institution, for it was realised from the start that its growth and strength would lie in the scientific training of young men about to enter the industry. It had been his task to see that the University of Birmingham took full cognisance of the new and growing industry. Events since, and the present high reputation of the University's Department of Petroleum Engineering, were ample proof of the wisdom of that step, and the great strides which had been made in such a comparatively short time.

It had to be remembered that the Institution's *Journal* had played a great part in the development of the Institution, and a debt was due to Dr. Dunstan and his colleagues.

He felt it a great honour to come back to the Presidential chair on the Institution's twenty-first birthday, and he assured members that any small part he could play in furthering its development and sustaining the high reputation it had acquired would be pleasure and a duty. In thanking members for the great honour they had done him, Sir John said that he hoped he would be able to live up to the excellent tradition which had been established by his predecessors in the Chair. He was especially appreciative of the great services Mr. Dewhurst had rendered the Institution

during the last two years. They had indeed been fortunate that at such an important period in their history—including the holding of the great World Petroleum Congress—they had had a man of Mr. Dewhurst's calibre to guide them. So greatly had he enhanced the reputation of the Institution by his presidency, Sir John said, that it was with more than usual warmth of feeling and gratitude that he asked members to join him in passing a most hearty vote of thanks to Mr. T. Dewhurst, their retiring President.

The resolution was carried with acclamation.

Mr. T. Dewhurst, in acknowledging the vote, said Sir John had already placed the members in his debt by his fascinating review of the early days of the Institution. Coming to a more personal matter, he thanked Sir John for his very kind but undeserved references to himself, and he thanked the members for their very generous reception of the vote of thanks. His own view was that he had been very fortunate in having occupied the Presidential Chair during a particularly interesting period in the history of the Institution.

DAVID WHITE, D.Sc.
Redwood Medallist, 1934.

[*To face p.* 301.

EFFECTS OF GEOPHYSICAL FACTORS ON THE EVOLUTION OF OIL AND COAL.*

By David White.

So far as the Author has taken part in discussions regarding the origin of petroleum, it has been mainly to point out some of the relations between coal and oil which must follow, or, at least, be considered, if it is believed that petroleum is of organic origin. The Author has persistently urged—and it is still worthy of insistence—that much can be learned about the genesis and distribution of oil by the examination of the phenomena connected with the origin and evolution of its sister product of organic sedimentation—coal.

In this paper, after reviewing some primary phases of the origin of petroleum, attention is especially directed to some conclusions and implications resulting from the examination of the progressive metamorphism of the chemically organic sediments, including coals and the "mother rocks" of oil. The evidence reviewed is, however, largely geological and circumstantial, rather than chemical.

At a very early stage in the work of studying the Carboniferous floras and coals, it became apparent that while minor differences between the coals of a given coal-field were due merely to differing proportions of the chemically different plant parts entering into the deposits, the greater and more important distinctions were due to differences in the stages of the progressive coalification of the vegetable débris—that is to say, of the so-called "*carbonisation*" of the bed. They are most easily shown by the increase in the fixed carbon (ash-, moisture-, and sulphur-free basis) observed on a regional scale in passing from locality to locality in a given direction in a single group of coals or, better, along a single coal-bed. These differences were generally found to be unaccompanied by any paleobotanical change; the same plants attended the coal-bed at localities of contrasting carbonisation. Similar progressive gradations in carbonisation were met in Mesozoic and Tertiary coal-fields, without corresponding changes in the ingredient vegetation or environment of deposition.

The conclusion was reached that the progressive carbonisation of the coal on a regional scale in any direction, accompanied as it is by progressive dehydration, lithification, refinement of cleavage, and increase of calorific value, represents incipient metamorphism;[1] that it must be due to progressive geochemical change induced or even controlled by geodynamic influences, and that it embraces the essential features of the evolution of the deposit from the rank of peat, at which bacterial action is assumed to have been suspended, to the final graphitic residues and fixed gases if the process has gone far enough.

Too frequently we overlook the fact that the metamorphism of chemically organic rocks begins with the initial changes in the chemical and physical

* Paper received November 28th, 1934.

states of the sedimentary deposits; chemical changes attending biochemical action in the newly-deposited débris, and those marking the long process of "devolatilisation"; physical changes beginning with progressive compression, lithification, dehydration, refractivity, and cleavage, together with such crystallisation and recrystallisation as may be incident to the chemical and physical changes.

If the entire scale of metamorphism comprises 100 units, the metamorphism of those rocks ordinarily termed "metamorphic" may be hypothetically conceived as falling between 60 and 100 on that scale, while the changes observed in the mother rocks of coal and of oil range between 0 and 70 and ordinary bituminous coals fall perhaps between 30 and 50. The above numbers have only relative value. Crystallisation, long known in oils, has also been observed, with changes of optical properties, in coals and oil shales.

In general, American geologists view coals as evolved from peats of various kinds. In other words, peats are regarded as the "mother rocks" of coals. Common banded coals had their origin in common woody peats, cannels in spore peats, and bogheads in alga peats laid down in deeper water. The organic débris contributed to the formation of ordinary peat is dominantly terrestrial, vascular, and characterised by its large carbohydrate component. In general also, American geologists view petroleum as derived from a related, though chemically somewhat different, organic mother sediment. This supposed mother rock of petroleum, sometimes classed as "kerogen" and "saprocol," is, on the other hand, more distinctly aquatic, and characteristically more or less fatty or highly hydrogenous, whilst many of its organisms are provided with "gelatinous" colloidal sheaths. It embraces very much plankton, including animal plankton as well as phytoplankton.* Both mother substances intergrade, depending on the environment of growth and, especially, deposition.[2]

The organic débris of either kind falling on the surface of deposition is immediately subject to bacterial and fungal attack, and is destructively decomposed and lost, unless the bacterial action and the accompanying biochemical processes are arrested by exhaustion of oxygen or generation of toxic products in sufficient amount. The microbian action is selective, and the composition of the remaining organic aggregate, which at the outset included many substances, some much more resistant to decay than others, is largely affected by the extent to which the biochemical processes have successively transformed or destroyed the different components.[3] The original chemical substances may accordingly be fully or but partly changed in the course of the biochemical action. The formation of fatty acid derivatives is characteristic of the biochemical action in the hydrogen-rich mother substance of oil, whilst humic acids in particular are developed in the oxygen-rich peat. As pointed out by Hammar, the

* The differentiation of coals in *types*, such as common banded coals, cannels, bogheads, or leaf coals, is due to differences in the ingredient matter as well as to the environment of deposition. Chemical distinctions based on these initial differences may continue to or nearly to the point of anthracitisation of the sediment, but these ingredient distinctions are clearly separable from those due to the stage of progressive carbonisation—*i.e.*, the *rank* of the deposit. Likewise, it is most logical and probable that certain differences in the qualities of the petroleums occurring in different regions or pools are similarly due to chemical differences in the ingredient mother rocks.

rôle of bacteria embraces the reduction of oxygen, nitrogen, and sulphur in the organic matter, thus apparently preparing it for the generation of petroleum, although the microbes do not themselves produce liquid hydrocarbons.[4]

Elimination of volatile matter, including methane, attends the biochemical processes with both sorts of mother rocks. Artificial distillation of the mother substance of oil at an early stage in the carbonisation of the deposits yields relatively larger portions of hydrocarbons of the oil series than from the supposed mother substance of coal. At all stages of natural carbonisation the characters of the distillates are closer to those of natural petroleums.

Obviously, after deep burial and cessation of bacterial action, the mother sediments of oil could not by any possibility escape the dynamic influences which simultaneously caused the carbonisation of the coal, and must have been similarly altered or transformed—a premise supported by abundant occurrences of highly carbonised or even graphitic shales and sandstones which must originally have conformed to our conceptions of the mother rocks of petroleum.

Chief among the geophysical factors causing the geochemical reactions resulting in the progressive carbonisation of the mother rocks of both kinds on a regional scale, in contrast to "contact" or local metamorphism, are: (1) pressure—mainly horizontal thrust pressure, of great duration and of varying intensity; (2) temperature, never actually high, except in contact metamorphism; and (3) time in the geologic sense. Pressure, which works truly impressive miracles in hydrocarbons, is substituted in amazing measures for temperature and time; and time appears more or less substitutable for pressure as well as to a remarkable extent for temperature. Additional factors, some of which may affect the geochemical processes and products, are depth of burial, catalysts, ionisation, contact chemical relations, enzymes, and still others, the functions and values of which remain to be determined.

A factor which is found most importantly to affect the regional carbonisation of coals is the degree of competency of the geological formations through which a given stress is transmitted. This is readily shown if lines of equal carbonisation * or "isocarbs" (ash-, moisture-, and sulphur-free basis) are drawn through a number of coal-fields in which the strata are either horizontal, or overthrust or folded on one side of the field, as in the Appalachian Trough. The examination of such "contouring" indicates very clearly that where competency has given strength to the crust to withstand the horizontal thrust so that the stress has been very gradually and but partly absorbed by compression in the course of its transmission, the carbonisation is higher and farther extended. On the other hand, where failure of the strata, as shown by buckling or overthrust, to withstand the same or perhaps a greater force has permitted the foreshortening of the arc of the crust and compensated the thrust force, thus enabling the beds, with the included coals, to escape the maximum compression, the carbonisation is lower. The effects of compensating or neutralising "breaks" are at once seen on both sides of thrust faults,

* "Isoanthracitic" lines of Strahan and Pollard.

and especially on the distal side, where the carbonisation is lower throughout a broad zone. The drop is normally greatest near the overthrust, but the fixed carbon over the whole width of the field behind a major thrust may not reach the level found in the uncompensated area.

Examples of the effects of competency as compared with failure of the strata to resist the thrust pressure will be found in many regions of relatively horizontal coal measures. Along the Choctaw fault, in Arkansas and Oklahoma, the fixed carbon of a group of coals drops 30 per cent. as the fold passes from a steep buckle to a great slice-overthrust near the front of the coal-field. The zone of relief, which is very narrow at the beginning, broadens as the overlap grows wider and, presumably, extends deeper.

Other things being equal, the carbonisation, or coalification, of the coal increases in the direction from which the horizontal thrust was administered, until it reaches the margin of the coal-field if the strata are competent. Areas of greatest carbonisation, on a regional scale, of the coal into the anthracitic and graphitic ranks are those in which the greatest thrust pressures were opposed by competent or relatively competent strata or structures.* Accordingly, "disturbed areas," including regions of closely folded rocks, may not be so far carbonised as contiguous areas in which horizontal, more competent beds have withstood the same or greater thrusting. It is highly probable that in most "disturbed" areas the coal reached its present stage of carbonisation before the strata gave way.

Studies of the relative effects of competency furnish the most obvious proofs of the great importance of horizontal thrust pressure as a factor in regional metamorphism, which in its incipient stages is especially well illustrated in coal-fields.

Next to be emphasised is that pressure and competency appear to play a comparable rôle in determining the characters of the oils in our oil-fields.

Accepting as inescapable the progressive regional devolatilisation of the mother rocks of both oil and coal, beginning with bacterial (biochemical) changes at time of deposition and continued geochemically under geodynamic influences underground, the Author made, in 1913, a graphic study of the stages of the regional carbonisation of coals with special reference to the presence and the qualities of the oils of pools in the same or closely associated formations or groups and in the same areas.[5]

This work proved to be of unexpected interest and value: First, as

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* The very striking compensatory effects of overthrusting in the western portion of the anthracite region of Pennsylvania, in South-western Virginia, in the Birmingham district of Alabama, and along the Choctaw fault in Oklahoma were pointed out in my paper on "Some Relations in Origin between Coal and Petroleum," *Washington Acad. Sci., Journ.*, 1915, **5**, 189–212; also in Day, D. T., "Handbook of the Petroleum Industry," p. 10, 1922.

The effects in South-western Virginia are illustrated in greater detail by Eby, J. B., *Bull. Amer. Assoc. Petr.*, 1923, **7**, 421–426; and by White, D., *op. cit.*, and "Environmental Conditions of Deposition of Coal," *Amer. Inst. Min. and Met. Eng., Trans.*, No. 1402, pp. 1–21, Jan., 1925.

The progressive carbonisation in the Pennsylvania anthracite region has been mapped by H. G. Turner (*Amer. Inst. Min. and Met. Eng., Trans.*, Feb., 1933), and the regional metamorphism of the Lower Kittanning coal-bed in Western Pennsylvania is described and mapped by T. Stadnichenko (*Econ. Geol.*, 1934, **29**, 511–543).

confirmatively illustrating the progressive regional devolatilisation (carbonisation) of the mother rocks of oil the ultimate residual of which is also graphitic and the progressive changes of which appear to go forward in the same direction as with the carbonisation of the coals; second, as pointing to a way by which both the presence or absence and the quality of oil may be more successfully predicted.

Using coal-field or State maps on which the "isocarbs" or contours showing lines of equal carbonisation of the coals had been drawn, tracings on translucent paper were made of the outlines of these coal-fields and of the contours. These tracings were then superposed on maps of the same areas and scale as before, on which the outlines of producing oil- and gas-fields had been drawn, with contouring of the Beaumé gravity of the oil in the pools. This mode of comparison showed more plainly than the Author had before been able to realise the general parallelism of the results of the progressive metamorphism of coals, on the one hand, and of the mother sediments of petroleum on the other. It was at once apparent that, in general, the rank of the oil in the field or pool corresponds roughly to the stage of the carbonisation of the organic sediment, as indicated by the fixed carbon in the coals of the associated or closely overlying geological formations in the same vertical section.

The grade (Beaumé gravity) of the oil was, in general, found to improve in the same direction in which increase of the fixed carbon of the coal was noted.

Oils indigenous to unaltered (in most cases young) formations in which the coals are brown lignites or very low-rank "black lignites," are usually of low rank, heavy and "asphaltic," with gravities below 25° Bé.

As the coals enter the "slacking" sub-bituminous ranks (moderate rank "black lignite") the *grade* of the oil normally rises, a gravity of 25° Bé. to 35° Bé. being usually found, whilst the oils corresponding to a low rank (high volatile) bituminous coal, which may "slack" a little, range normally around 32–39° Bé. Above this the grade of the oil rises with the advancing carbonisation, with increases in the calorific value of the coals (38–45° Bé. on the western side of the Appalachian Trough; 45–48° Bé. on the eastern side, locally reaching 52° Bé. at the eastern border), until what may be termed the *extinction zone* of the oil-field is reached.

The *extinction zone* is a narrow zone lying approximately between the 59 per cent. and the 64 per cent. fixed carbon lines, drawn on the coals of the associated or closely overlying formations. Oil-pools beyond the 59 per cent. line are rare and small, and generally of little commercial importance, although the oils themselves are of very high rank, or even "white," approaching gasoline in composition. Examples of such "twilight zone" pools are seen near Fort Smith, Ark., the Rattlesnake field (gasoline) in North-western New Mexico, and in Alberta. Within this zone the oil seems to fade as if volatilised underground, although gas in commercial amounts may fill favourable structures in regions far beyond the oil-pools, in which the associated coals of uniform origin and possibly belonging to the same series or the same bed have reached the ranks of smokeless coals and even anthracites.

The Author can recall no region where commercial oil-pools lie in or

closely beneath a formation in which the fixed carbon of the coals in the same vertical section exceeds 66 per cent. Many American geologists and engineers hesitate to recommend the hazard of drilling when the carbonisation exceeds 62 per cent. The extinction zone for commercial oil deposits falls near the lower limits of the group of coals once favoured for old-style beehive oven coke production.

The present undesirable width of the extinction zone is due in part at least to: (*a*) differences in the age, or in the stratigraphic distance between the coal and the oil zone used in the comparison; (*b*) the use of weathered or partly oxidised coals; (*c*) lack of international standardization of the empirical method of determining fixed carbon; (*d*) the error, generally not exceeding 1 per cent., in the determination of the fixed carbon of the coal; (*e*) very large proportions of fusain, "mineral charcoal," in the coal, causing high fixed carbon; or (*f*) of fatty matter, such as spore exines or fatty algæ, which may cause an abnormally low fixed carbon in a coal. An exceedingly large amount of fusain in a banded coal of the 60 per cent. fixed carbon rank may cause an excess of 5 or 6 per cent. in the fixed carbon, whilst a very nearly total lack of fusain may cause a deficiency of as many per cent.* On the other hand, while a very good fatty cannel coal in the same section with a normal coal of 55 per cent. rank might give but 45 per cent. of fixed carbon by the standard analysis, a very notable excess of the cannel exines mingled or intercalated in a banded coal of 60 rank would be required to account for a 5 per cent. deficiency of fixed carbon. No geologist or engineer in the least familiar with cannel or boghead types of coal is likely to sample either of the latter without recognising it. In most cases moderate excesses or deficiencies of fusain or cannel matter will not cause respective variations of more than 3 per cent. plus or minus in the fixed carbon of a coal of the 60 per cent. rank.

There can be but little doubt that the extinction zone can and will be more narrowly defined, at least in many regions, as more closely standardized criteria are used in defining it, and present sources of error are counteracted. Some variation on either side of the narrowed zone may, however, be due to differences in the composition of the mother rock, and, consequently, in the point in its carbonisation at which its volatile products cease to be liquid at atmospheric pressure and temperature. At present, on the basis of observational evidence, it would appear that, under conditions yet to be ascertained, the lower limits may eventually prove to be not lower than 60 per cent. fixed carbon in most regions, and that 64 per cent. is higher than the normal or average upper limit, even as indicated by data now available; for the Author cannot in all cases vouch for the character or conditions of the coals the analysis of which he has used.

Consistent with the betterment of the oil in the same direction, and parallel with the increase in the carbonisation and calorific value of the coals, the Beaumé improvement was found, as noted in 1915, to extend also in the downward direction, in conformity with the law of Hilt, as pointed out independently by Engler and others, including the Author.

* The fixed carbon of a glistening fibrous fusain, isolated and analysed separately, may approximate 85 per cent.

The Author confesses here, with some chagrin, that it was only long after 1915 that he learned that the eastwardly progressive metamorphism of the coals, and the improvement of the oils in the same direction, and even in the vertical sense in the northern portion of the Appalachian Trough, had been noted more than two generations earlier by one of the great geologists of his day, H. D. Rogers. Rogers, in 1843,* pointed to the progressive metamorphism of the coals, heat and hydrothermal influence being cited as the causes; and in 1860, when explaining the oils as products of the distillation of the coals and other organic sediments, he remarked on their eastward betterment, due to the same causes which completely eliminated them before the coals reached the anthracitic stage.† His theories as to causes and processes, although plainly vulnerable, reflect geological conceptions some of which were greatly in advance of previous hypotheses.

The application of the law of Hilt to the mother rocks of petroleum and their products furnishes a basis useful in formulating conclusions as to the possible age of the formation tapped by the drill, or as to the depth from which oil may have migrated ‡ to reach its present storage. Later, when the controlling conditions are better understood, it may also be of use in forecasting depths beyond which oil stable at atmospheric pressure and temperatures should not be found.

From the fact that the supposed mother rocks of petroleum as now found in many regions give off condensable vapours when distilled, unless too far altered, the amounts and the qualities being found in each case to correspond to some extent to the stage of carbonisation of the rock,

* " . . . the loss of volatile matter which marks the different degrees of 'debituminisation' of the coals was caused by the prodigious quantity of intensely-heated steam and gaseous matter emitted through the crust of the earth by the almost infinite number of cracks and crevices which must have been produced during the undulation and permanent bending of the strata" (*Trans. Amer. Assoc. Geol. and Natur.*, 1843, **2**, 433–474).

† " . . . referring to his repeatedly published views of the volatilising and discharging agency of subterranean steam, issuing hot and dry through the crevices of the strata, during convulsive earthquake upheaval and oscillation of the coal measures, he infers that the petroleum and burning gas of Western Pennsylvania and Western Virginia were extricated or distilled from the already-framed hydrogenous coal seams, and merely not wholly expelled into the atmosphere as in the anthracite region, but arrested in the pores and crevices of the overlying strata at a stage short of their total expulsion. In the districts south-east of the oil-producing tract these volatile matters were not only set loose from the coal by the chemically decomposing function of the compressed hot steam, but were dislodged from the strata altogether by its well-known carrying agency . . ." ("On the Distribution and Probable Origin of the Petroleum, or Rock Oil, of Western Pennsylvania, New York, and Ohio"; *Proc. Phil. Soc. Glasgow*, 1860, **4**, pp. 355–359).

" . . . These compressed deeper-seated materials are also under a closer imprisonment than the more superficial ones, from the greater pressure of the incumbent very weighty strata resting over them. From both sources, the higher heat and the greater pressure, they are in a state of far more compression than the heavier petroleums, already refined and distilled upward into the cooler and less pressed-upon rocks nearer the surface. Thus we see why these upper heavier petroleums are what they are;—they were permitted, long ago, to part with nearly all their elastic gases and their readily vaporised lighter oils . . ." ("On Petroleum": *Proc. Phil. Soc. Glasgow*, 1866, **6**, No. 2, 50–51).

‡ Evidences of such migration are found in some of the salt domes in the Coastal Plain of Texas, in which the salt-plugs may have risen from beds of Permian age, apparently leading petroleum deposits along with them, or tapping deposits of later age and inferior quality along the upward route.

it would appear that the oil derived by natural processes from the organic sediments was not all generated in the sediments at one time. Further, the experiments carried out some years ago under the auspices of the American Petroleum Institute, with the advice of the National Research Council, seem to leave extremely little ground for the theories (1) that petroleum of commercial types was generated at time of deposition of the organic débris or before the suspension of bacterial action; or (2) that petroleum is generated in the living plant or animal matter and brought by it to the scene of the organic sedimentation. More than 2000 bottom samples, mainly from continental shelves of regions in many parts of the world chosen as theoretically favourable for the deposition of mother sediments of oil, were examined with special reference to the occurrence of liquid hydrocarbons by Parker D. Trask,[6] who states "No liquid hydrocarbons were observed in any of the extracts of these sediments richest in organic matter found in our survey of practically the entire world."

The rôle of diatoms in particular as sources of oil, either through the storage of petroleum-like hydrocarbons in the living plant cells, as has been reported by Albert Mann, or as generated in the recently deposited diatom débris in the course of the biochemical decomposition of the organisms, was rather fully tested by two investigators, T. Hashimoto and Lewis A. Thayer, working under the direction of C. F. Tolman [7] and L. B. Becking.

Large piles of diatoms annually washed ashore near Copalis Beach, Washington, were available for investigation. Oil, formed as reserve food in the plant cells, was found in rather large amounts, which, by choice of nutrition in the laboratory, were increased to as much as 39 per cent. of the weight of the living organism. Further, both the accumulated diatom deposits on the beach and large samples taken to the laboratory were tested to ascertain whether oil was produced biochemically in the course of their decomposition, the decay of the laboratory samples being under control. Hashimoto found "The varieties of hydrocarbons constituting the natural petroleum deposits are not synthesised as such by diatoms," while Thayer reported that the decomposition tests furnished no proof that petroleums are generated during the process of decomposition of diatom deposits that goes forward as they are buried in the sediments.

If the observations cited on previous pages are valid—it is practicable to confirm them in many regions—both the progressive carbonisation of coal and the evolution of petroleum are accomplished under geophysical influences or control by processes equivalent to natural underground "cracking" of organic mother substances in the sediments. Pressure is of dominant importance in the subterranean environment, as well as in the laboratory, where, however, higher temperatures are required to do work that is done by aid of time of geologic length in the natural process.

According to this interpretation, progress in the metamorphism and consequent devolatilisation of the organic sediments was accomplished, as with the inorganic sediments, mainly at least, at times of orogenic movements, with their intermittently increased stresses, concomitantly attended by relatively higher (although not necessarily high) temperatures, exerted through considerable periods. Each such advance of pressure, presumably with an increment of heat, to a degree higher than that previously

experienced in the beds and area should cause "cracking," with the production of lighter volatile hydrocarbons, and advances in the carbonisation, marked by concentration of carbon in increasingly heavy molecules, in the solid residues.

These conclusions are in harmony with the long known principle of the advance of the point of thermal decomposition to accord with the advance in the stage of the carbonisation of the organic deposits. This has recently been shown experimentally with precise determinations of the points of thermal decomposition of coals by R. V. Wheeler [8] and J. E. Ashmore, and of mother rocks of oil by T. Stadnichenko.[9] It was found by Stadnichenko not only that evolutions of volatile matter from the mother rocks of petroleum occurred in several zones as the temperature was progressively raised, but also that some, at least, of the points of decomposition varied with the kinds of the organic matter, as well as with the stage of natural carbonisation of the material selected for the test.

Consequent to the varying composition of the mother rocks it may be concluded that some oils are probably generated at lower pressures or temperatures than others, and that oils of different characters may possibly have been generated at the same pressure and temperature. In general, however, the final yields of oil, as carbonisation passes into the extinction zone, are very light and of similar composition. Presumably, also, they are produced at, or very nearly at, the same stage of progressive metamorphism or cracking.

The natural "cracking" to which the mother sediment of petroleum was certainly subjected simultaneously with the coals must have also affected oil deposits held sealed in pressure storage and amenable to increased pressure and temperature with each advance of orogenic stress. Further genesis of hydrocarbons lighter than before should accordingly take place under "cracking," both from the mother rock and from the stored oil. Under these new and higher pressures old oils should absorb portions of the new and lighter products, with consequent effects of beneficiation and enrichment. That this occurred seems logical and highly probable.

In these directions lie the explanations: (1) of the presence of successively higher rank (Beaumé gravity) oils in the areas of greater actual rock compression, as shown by the greater carbonisation of the coals brought about through repeated orogeny of growing intensity; (2) of the development of a final "extinction zone" in which the mobile hydrocarbons are reaching the point where they are no longer condensable at atmospheric pressure and temperatures; (3) of the presence of natural gas-fields beyond the "extinction zone" in regions of greater carbonisation; and (4) of the progressive losses of volatile matter, especially hydrogen, with consequent depreciation of thermal value of the coals as they advance through the anthracitic and semi-graphitic ranks.

Petroleum, with its variable characters, is, we may agree, the joint product of: (1) sedimentary deposits of organic mother substances of somewhat variable composition; (2) biochemical change of the mother substances, varying in kind and extent with the composition of the original organic matter and the conditions of deposition; and (3) geochemical changes which take place underground in the course of time under (4)

geophysical influences, and which probably vary with the ratios of pressure, temperature, and time. Further, as found the oil may have been modified by leakage of its lighter components; by contamination; by reaction with associated inorganic as well as organic substances; by oxidation, and by filtration. All these invite experimental research.

Continued examination, in particular, of the geochemical changes, jointly with the local geologic history and the attending geophysical conditions, should explain many of the anomalies and exceptional cases now baffling petroleum students, and lead to a sounder and clearer understanding of the really exciting history of the chemically organic matters buried as sediments in the earth's crust.

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